Spacelab Life Sciences 1

First Space Laboratory Dedicated to Life Sciences Research

NASA

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First Space Laboratory Dedicated to Life Sciences Research

NASA
National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center

NP 120

A Legacy of Space Life Sciences Research

When the decision was made to explore space, some people were skeptical. Could human beings live in a world virtually without gravity? Did space harbor dangerous organisms? What would happen to plants and animals exposed to weightlessness? In 30 years of space flight experience, we have learned that people can live and work productively in space.

Before human beings went to space, animals were sent as surrogates. Instruments monitored various physiological responses as the animals experienced the stresses of launch, reentry, and the weightless environment. Paving the way for human expeditions, the first animal space travelers returned to Earth in healthy condition, refuting predictions that some vital organs might not function in the low-gravity environment.

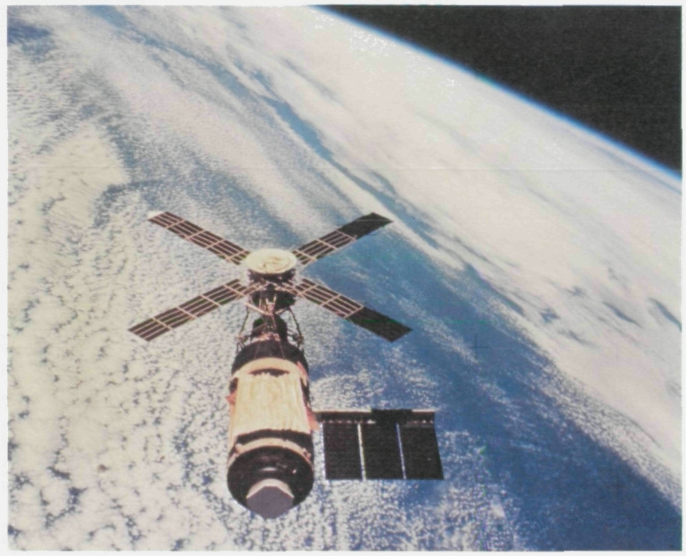
America's first astronauts completed solo flights of up to 2 days in the relatively small Mercury capsules. After they returned safely, medical scientists dismissed many of the concerns about the frailty of the human space explorer. However, the Mercury flights made it apparent that the body undergoes some changes, such as weight loss and fluid redistribution.

Mercury missions (1961-1963)

Life sciences studies were important in preparing the space suit and equipment needed for survival on the first U.S. space walk during Gemini 4. Astronauts completed a more complex set of inflight medical studies during the Gemini missions, which served as preludes to the lunar excursions. Doctors observed additional physiological changes (such as minimal loss of bone and muscle density) but discovered no substantial health problems to prevent humans from traveling to the moon.

Gemini missions (1965-1966)

Apollo missions (1968-1972)



Skylab missions (1973-1974)

Astronauts worked quite productively on the moon in only one-sixth the gravity of Earth. While the Apollo missions included simple inflight observations, doctors examined crew members primarily before and after each flight. During the flights, crew members reported a few minor physiological problems, such as space motion sickness (which has some of the same symptoms as Earth motion sickness), but once again humans were able to live and work effectively in space without experiencing any major physiological problems.

During these early missions, scientists began to learn about human responses to microgravity. However, the small Mercury, Gemini, and Apollo spacecraft had little room for research equipment. Scientists were able to make more detailed measurements during three missions lasting 28, 59, and 84 days aboard Skylab, America's first space station. The most important contribution of these missions was to prove that people can live and work in space for several months. Astronaut-scientists conducted investigations on board the large orbiting facility (about the size of a five-room house), where there was more room for the precise research equipment needed to study the effects of living in weightlessness.

Skylab experiments gave scientists a basic picture of how individual parts of the body, such as the heart, muscles, bones, and blood cells, respond to weightlessness. But there was still no explanation for some responses and no complete picture of the interrelationship of reactions from different parts of the body. Like many pioneering efforts, Skylab left researchers with a multitude of new questions. Though initial progress was made, the real effort still lay ahead.

During the years between Skylab and Shuttle investigations, life scientists developed detailed plans for studying the whole body's response to space flight while also examining how microgravity affects individual parts of the body. The Spacelab Life Sciences 1 mission is the first opportunity since Skylab to make interrelated physiological measurements in space. ■

The National Aeronautics and Space Administration (NASA) Life Sciences Program has three main goals:

- **Understand the origin, evolution, and distribution of life in the universe**
- **Understand the relationship between life and gravity and other planetary properties**
- **Develop medical and biological systems that enable the human exploration and habitation of space.**

The Spacelab Life Sciences 1 mission is part of this vigorous inquiry to study the nature of life, ensure the success of human space flight, and bring the benefits back home to Earth.

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The cover art and paintings depicting experiments for the cardiovascular/cardiopulmonary system, the renal/endocrine system, the musculoskeletal system, and the neurovestibular system are the work of artist Frank Kulczak of Hanover, Pennsylvania.

Contents

Introduction

Successful exploration of space depends on the health and well-being of people who travel and work there. For this reason, the National Aeronautics and Space Administration (NASA) has dedicated several Shuttle missions to examine how living and working in space affects the human body. Spacelab Life Sciences 1 (SLS-1) is the first of these missions.

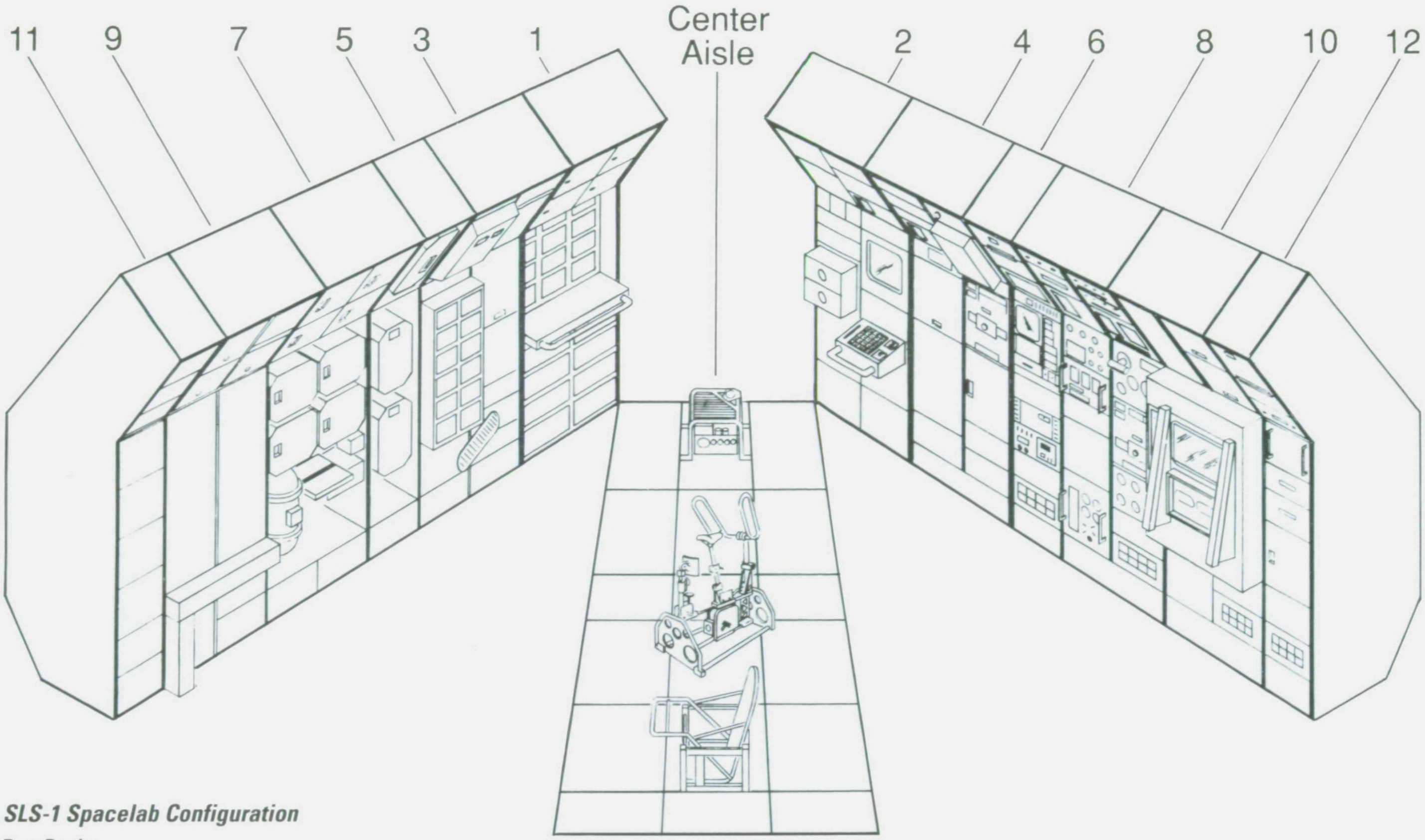
The main purpose of the SLS-1 mission is to study the mechanisms, magnitudes, and time courses of certain physiological changes that occur during space flight and to investigate the consequences of the body's adaptation to microgravity and readjustment to 1-g. How does space flight influence the heart and circulatory system, metabolic processes, the muscles and bones, and the cells? If responses are undesirable, how can they be prevented or controlled? Will the human body maintain its physical and chemical equilibrium during months aboard a space station and years-long missions to Mars? When crews return to Earth, what can they expect to experience? With the SLS-1 experiments, NASA is addressing some of these questions.

The SLS-1 investigations explore the responses of the heart, lungs, blood vessels, kidneys, and hormone-secreting glands to microgravity and related body fluid shifts; examine the causes of space motion sickness; and study changes in the muscles, bones, and cells. Procedures and equipment for space biomedical investigations are also tested. These tests are essential to developing an effective and efficient laboratory for life sciences research on Space Station Freedom.

Much of the SLS-1 research not only scrutinizes the physiological effects of space travel but also has the potential to help us comprehend medical disorders experienced on Earth. Cardiovascular experiments may help scientists learn more about disorders such as hypertension and heart failure, and musculoskeletal investigations may increase insight into bone diseases such as osteoporosis, muscle disorders, and the vital role of force and pressure on musculoskeletal structure and metabolism. Although these experiments were not designed specifically to deal with medical problems on Earth, their findings will further define body functions being examined on the ground and in space.

Earth's many life forms evolved under the influence of gravity; in microgravity, biological systems function differently.

The Space Shuttle carries Spacelab to orbit.



SLS-1 Spacelab Configuration

Port Racks

Rack 1:	Workbench
Rack 3:	Research Animal Holding Facility
Rack 5:	SMIDEX single rack Jellyfish experiment Space Acceleration Measurement System
Rack 7:	SMIDEX double rack Solid Surface Combustion Experiment Noninvasive Central Venous Pressure Intravenous Infusion Pump American Flight Echocardiograph Surgical Work Station
Rack 9:	Refrigerator/Freezer Small Mass Measurement Instrument
Rack 11:	Baroreflex Neck Pressure Chamber and electronics Rotating Dome Incubator Low-g Centrifuge

Center Aisle

Body Restraint System

Bicycle Ergometer

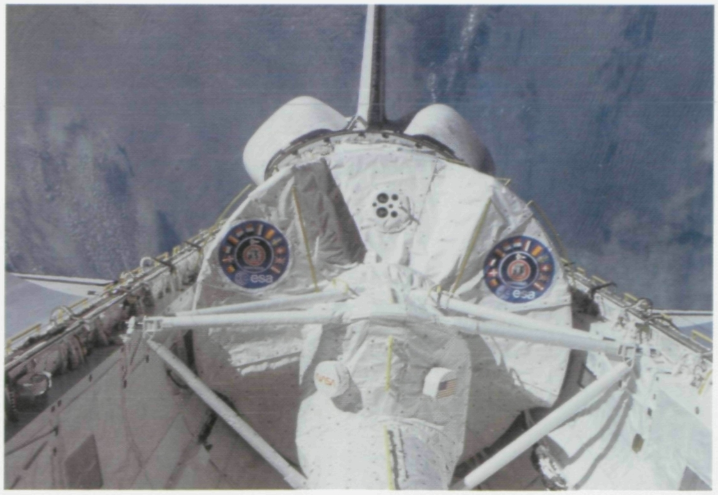
Body Mass Measurement Device

Starboard Racks

Rack 2:	Control Center
Rack 4:	Television and video monitoring equipment Spacelab support services Gas Analyzer Mass Spectrometer
Rack 6:	Echocardiograph Experiment Command and Data System/Microcomputer System
Rack 8:	Gas Analyzer Mass Spectrometer Rebreathing Assembly Unit Life Sciences Laboratory Equipment (LSLE) Microcomputers Vacuum Interface Assembly Video Monitor Cardiovascular/Cardiopulmonary Interface Panel Cardiopulmonary Control Unit Gas Tank Assembly
Rack 10:	General Purpose Work Station
Rack 12:	LSLE Centrifuge

SLS-1 Mission Facts

Launch Site:	**Kennedy Space Center, FL**
Shuttle Orbiter:	**Columbia**
Insertion Altitude:	**160 nautical mi. (184 statute mi.)**
Operational Altitude:	**150 nautical mi. (173 statute mi.)**
Orbital Inclination:	**39°**
Mission Duration:	**9 days**
Prime Landing Site:	**Edwards Air Force Base, CA**
Alternate Landing Site:	**Kennedy Space Center, FL**



Spacelab is a laboratory built for NASA by the European Space Agency.

The SLS-1 Laboratory

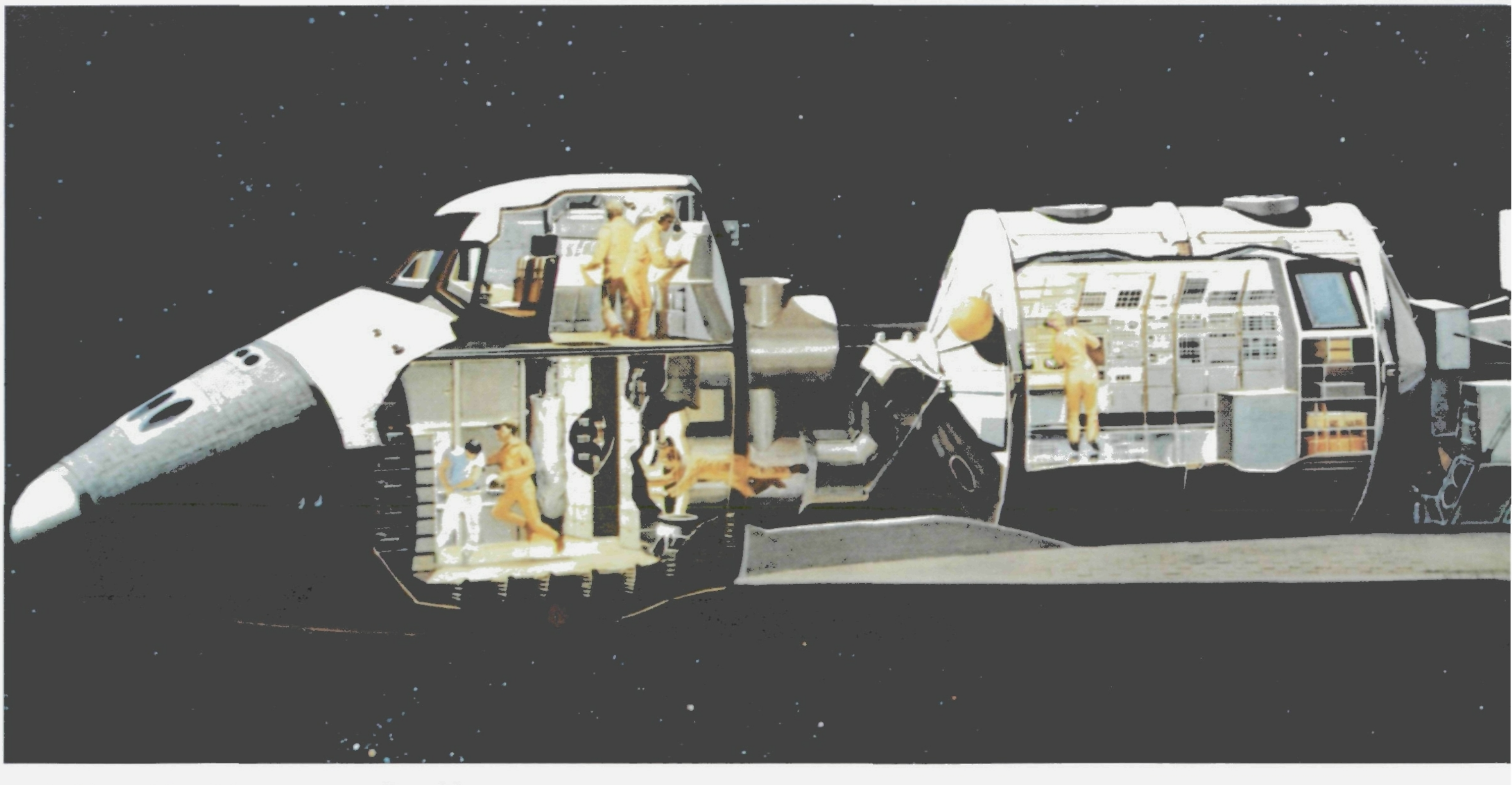
Spacelab is a reusable laboratory carried in the Shuttle payload bay. For most of the previous Spacelab missions, experiments in several different disciplines such as astronomy, life sciences, and materials science shared the modular laboratory. SLS-1 is the first mission to convert Spacelab into a biological research center.

Experiments are done in an enclosed pressurized Spacelab module, a cylindrical room that is 23 feet (7 meters) long and 16 feet (5 meters) wide, about the size of a bus. This module contains utilities, computers, work areas, and instrument racks for experiments. The crew enter it through a tunnel connected to the Shuttle middeck.

For SLS-1, NASA is outfitting the Spacelab module with instruments routinely found in biomedical research laboratories. The equipment is mounted in 12 racks that extend from the floor to the ceiling along the sides of the module, in 14 overhead lockers, and in the center aisle of the module. Some of the smaller equipment is located in middeck lockers.

For this dedicated life sciences mission, investigators coordinate their research and share equipment, minimizing hardware development. Most of them use NASA Life Sciences Laboratory Equipment, an inventory of multipurpose, reusable medical and biological instruments that have been developed or modified for use in microgravity. This equipment includes animal holding facilities, refrigerator/freezers, small and large mass measurement devices, and a special work station. These basic research instruments are augmented by unique equipment designed for particular investigations, such as cardiovascular and cardiopulmonary testing apparatus and cell incubators.

SLS-1 is the first mission to use the Spacelab Middeck Experiments (SMIDEX), a facility for housing experiments that fit in middeck lockers. It allows extra space inside the laboratory to be used for several small experiments. ■



A scientist completes an experiment in the Spacelab module, while another moves through the tunnel that connects the laboratory with the middeck living quarters. Other crew members work in the cockpit and aft flight deck.

Space Medicine and Biology

We take gravity for granted. In the space environment, which is virtually without gravity, we gain new insight into gravity's subtle relationship with living organisms.

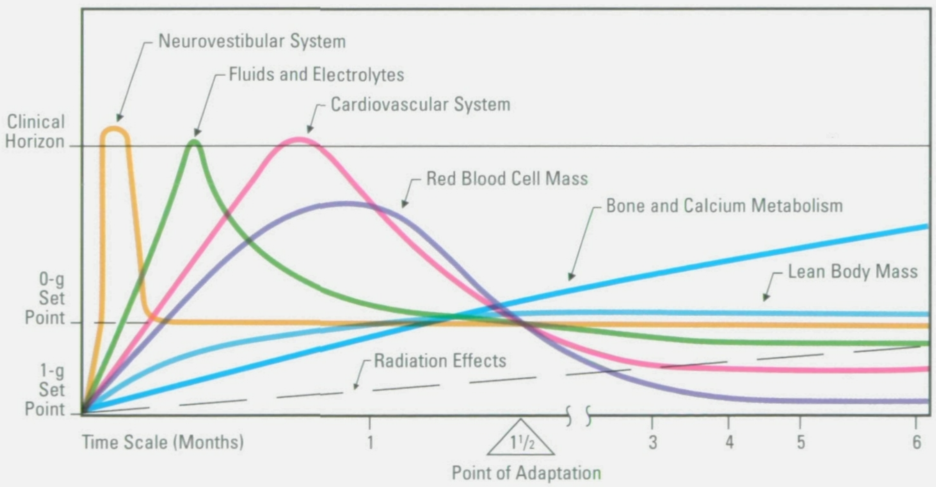
On Earth, the body normally operates in a steady state; blood pressure, fluid content, and other physiological conditions stabilize at particular set points. In space, the body adapts by establishing a new balance. Previous missions have identified physiological changes linked to this adaptation: body fluids are redistributed, space sickness may occur, and other more slowly changing systems, such as muscle and bone, begin to respond to microgravity exposure. None of the findings to date suggests that any of the body's responses are serious.

Although these changes may be part of the body's natural adaptation to microgravity, they may not be harmless, because the body must readjust to gravity upon return to Earth. Following a short period of readaptation to 1-g, the changes appear to reverse. However, after longer flights (more than 6 months), the readaptation process may require a significant rehabilitation period. Possibly, people may experience irreversible changes during repeated or longer exposures to space. If this is the case, NASA must determine the best ways to prevent adverse effects.

Current data suggest that physiological disturbances begin in the initial hours of space flight when fluids are redistributed in the body. On Earth, blood tends to pool in the feet and legs, and passive physiological responses (such as intermittent muscle contractions) force blood back to the heart. Scientists believe that in space fluid no longer pools in the lower extremities and larger than normal amounts of fluid accumulate in the chest, neck, and head. To relieve increased pressure caused by fluid shifts, the organs that regulate body fluid volume (the endocrine glands and the kidneys) remove what appears to be excess fluid. SLS-1 experiments define the events that lead to the redistribution of blood and other fluids and identify how the heart, the lungs, the renal/endocrine system, and the rest of the body respond.

Another disturbance that sometimes occurs and subsides in the first few days of a mission is space motion sickness, which has some symptoms similar to Earth motion sickness and has affected about half of all astronauts. SLS-1 investigators want to discover the causes of space motion sickness and further define its effects on the body.

Muscle atrophy, bone deterioration, and cellular disturbances may continue indefinitely. However, these effects begin



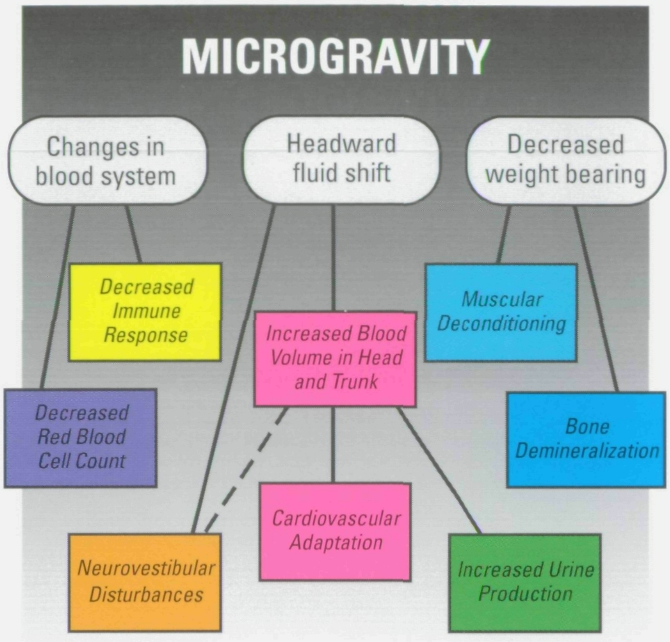
Each physiological system acclimates to microgravity at a different rate.

immediately after microgravity exposure and can be studied even on short Shuttle missions. SLS-1 investigations measure changes in muscles and bones and examine red blood cells and white blood cells.

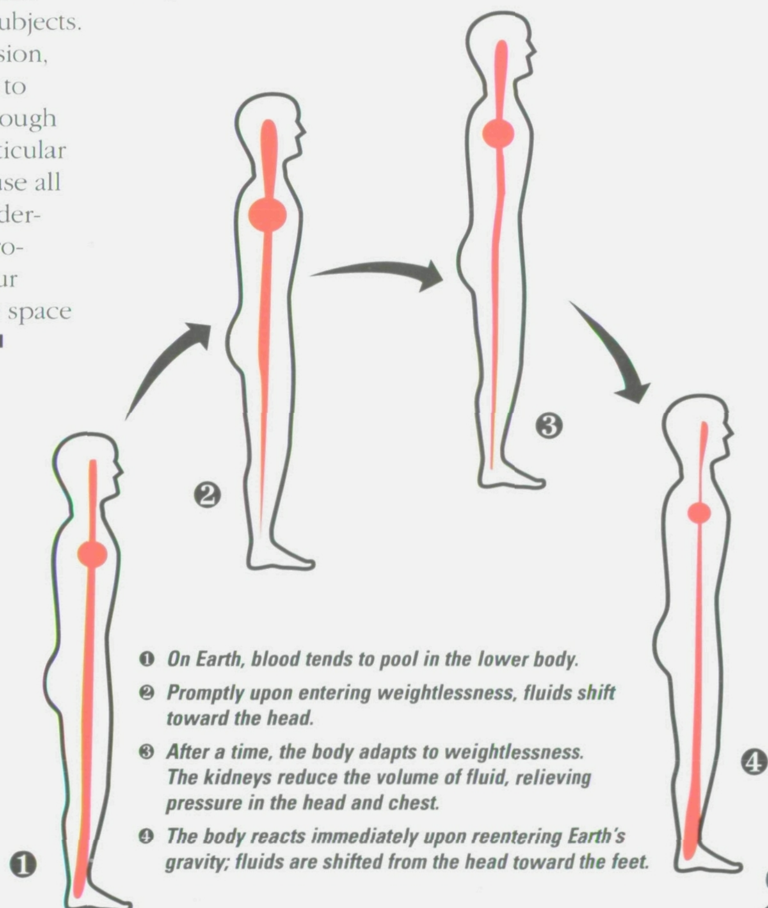
SLS-1 research builds on information collected during other missions and ground-based studies. Some SLS-1 investigations repeat measurements recorded on previous missions, but many measurements are made for the first time. To follow the time course of adaptive processes, experiments are done at specific times and at regular intervals before, during, and after the mission. This is the first time measurements are made so soon after launch, immediately upon exposure to weightlessness. Data collected during the first two days of the mission will be particularly valuable for understanding the events that initiate changes in the body.

SLS-1 scientists compare the physiological systems of different species. Studies with rodents and jellyfish are designed to see whether they have some of the same responses measured in people and to provide critical data that are unavailable from human subjects.

With this dedicated life sciences mission, scientists are making a concerted effort to study the human body as a whole. Although each experiment concentrates on a particular aspect of space medicine, researchers use all measurements to obtain a thorough understanding of the body's response to microgravity. Without this type of analysis, our understanding of how life adapts to the space environment will remain incomplete. ■



Major physiological systems interact as the body adapts to weightlessness.



❶ On Earth, blood tends to pool in the lower body.

❷ Promptly upon entering weightlessness, fluids shift toward the head.

❸ After a time, the body adapts to weightlessness. The kidneys reduce the volume of fluid, relieving pressure in the head and chest.

❹ The body reacts immediately upon reentering Earth's gravity; fluids are shifted from the head toward the feet.

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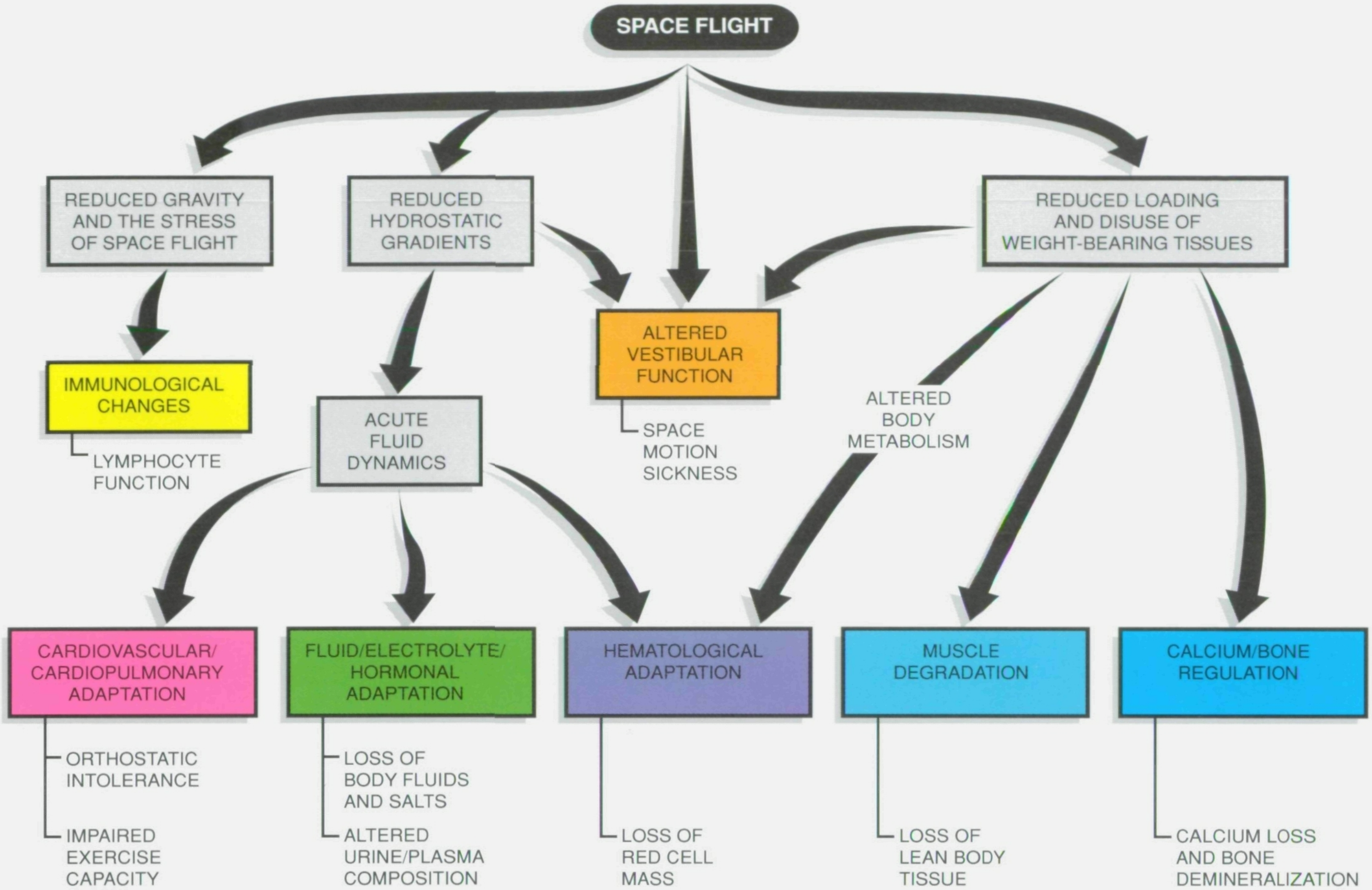
Investigations Summary

Research Area	Experiment Number & Title		Principal Investigator
Cardiovascular/Cardiopulmonary System	294	Cardiovascular Adaptation to Zero Gravity	Dr. C. Gunnar Blomqvist
	066	Inflight Study of Cardiovascular Deconditioning	Dr. Leon E. Farhi
	198	Pulmonary Function During Weightlessness	Dr. John B. West
	022	Influence of Weightlessness Upon Human Autonomic Cardiovascular Control	Dr. Dwain L. Eckberg
	248	Cardiovascular Adaptation of White Rats to Decreased Gravity of Space Shuttle/Spacelab	Dr. Vojin P. Popovic
	166	Correlation of Macro- and Microcirculatory Alterations During Weightlessness	Dr. Phillip M. Hutchins
Renal/Endocrine System	192	Fluid-Electrolyte Regulation During Space Flight	Dr. Carolyn S. Leach
Blood System	261	The Influence of Space Flight on Erythrokinetics in Man	Dr. Clarence P. Alfrey
	141	Regulation of Blood Volume During Space Flight	Dr. Clarence P. Alfrey
	012	Regulation of Erythropoiesis in Rats During Space Flight	Dr. Robert D. Lange
Immune System	240	Lymphocyte Proliferation in Weightlessness	Dr. Augusto Cogoli
Musculoskeletal System	120	Protein Metabolism During Space Flight	Dr. T. Peter Stein
	127	Effects of Zero Gravity on Biochemical and Metabolic Properties of Skeletal Muscle in Rats	Dr. Kenneth M. Baldwin
	303	Effects of Microgravity on the Electron Microscopy, Histochemistry, and Protease Activities of Rat Hindlimb Muscle	Dr. Dan A. Riley
	247	Skeletal Myosin Isoenzymes in Rats Exposed to Zero Gravity	Dr. Joseph Foon Yoong Hoh
	305	Pathophysiology of Mineral Loss During Space Flight	Dr. Claude D. Arnaud
	194	Bone, Calcium, and Space Flight	Dr. Emily M. Holton
Neurovestibular System	072	Vestibular Experiments in Spacelab	Dr. Laurence R. Young
	238	A Study of the Effects of Space Travel on Mammalian Gravity Receptors	Dr. Muriel D. Ross
	DCL*	Effects of Microgravity-Induced Weightlessness on Aurelia Ephyra Differentiation and Statolith Synthesis	Dr. Dorothy B. Spangenberg

* This experiment was proposed in response to a Dear Colleague Letter (DCL) and, as such, is not assigned an experiment number.

The Science Payload



SLS experiments will help define the relationships between various physiological systems and gravity.

Twenty SLS-1 investigations study six body systems:	
Cardiovascular/Cardiopulmonary System (heart, lungs, and blood vessels)	
Renal/Endocrine System (kidneys and hormone-secreting organs)	
Blood System (blood plasma and red blood cells)	
Immune System (white blood cells)	
Musculoskeletal System (muscles and bones)	
Neurovestibular System (brain and nerves, eyes, and inner ear).	
Other Investigations	perform functional tests of hardware and operations that are pertinent to the future of the space life sciences program.

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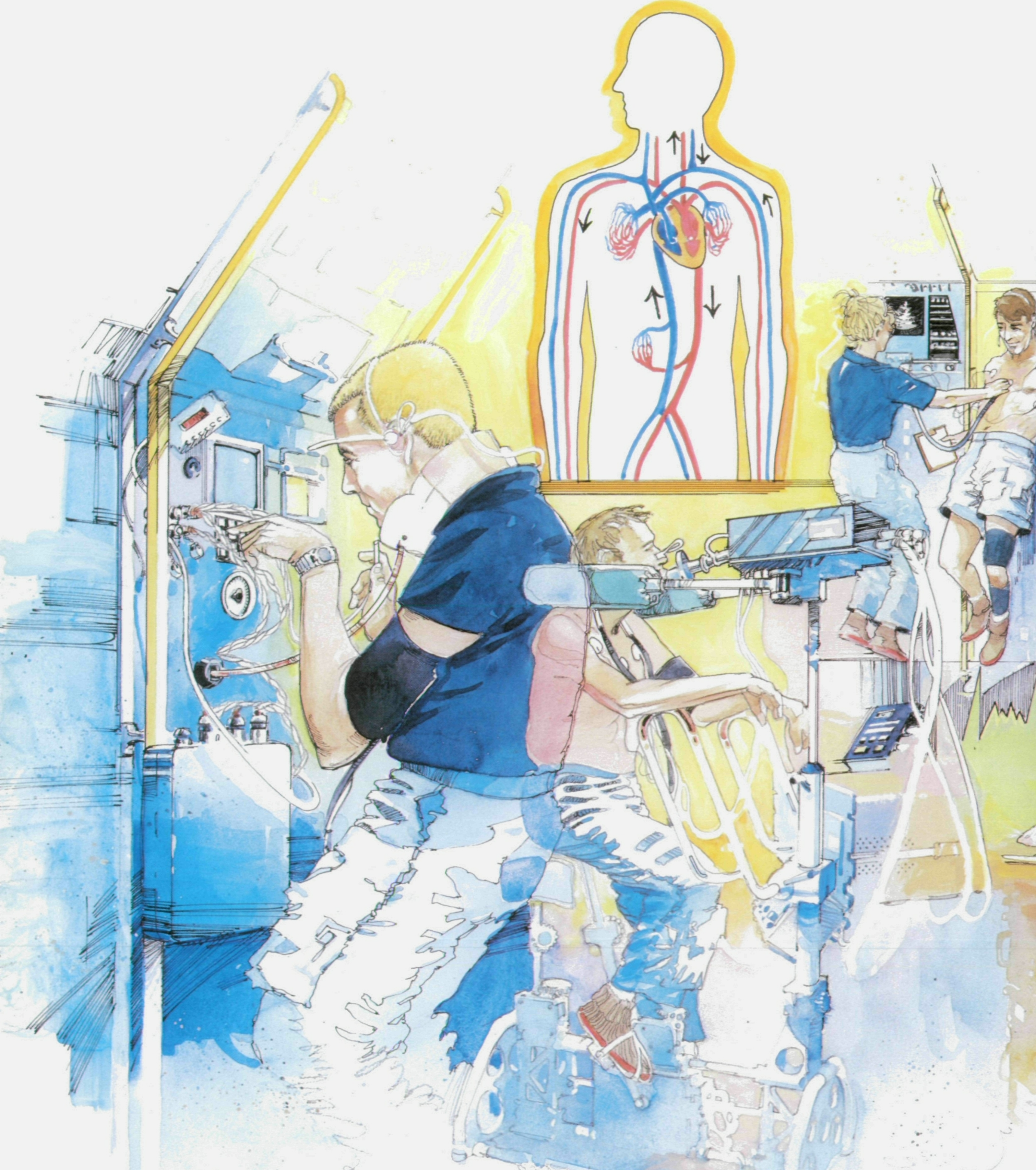
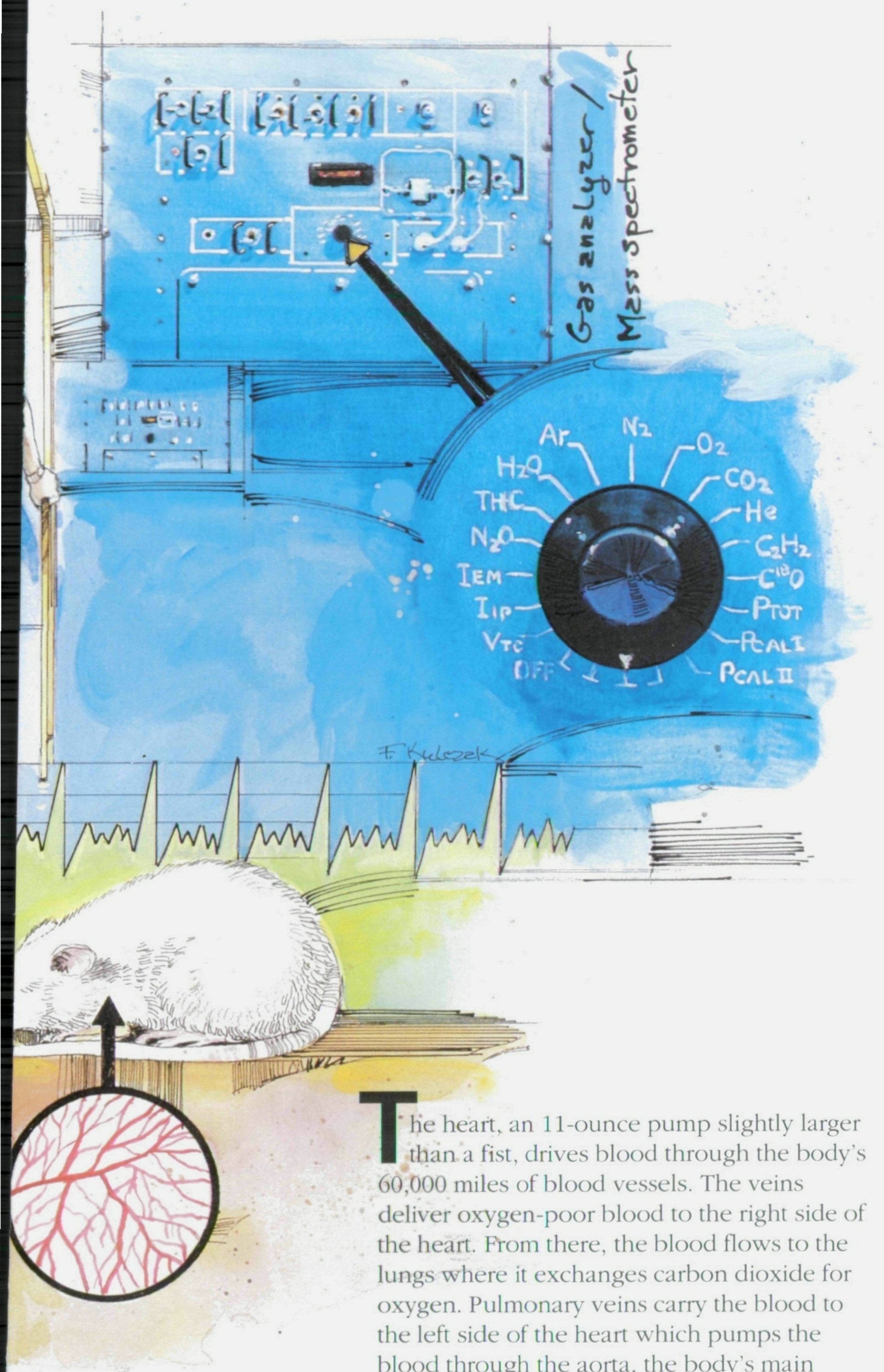


The Cardiovascular/Cardiopulmonary System: Heart, Lungs, and Blood Vessels



The heart, an 11-ounce pump slightly larger than a fist, drives blood through the body's 60,000 miles of blood vessels. The veins deliver oxygen-poor blood to the right side of the heart. From there, the blood flows to the lungs where it exchanges carbon dioxide for oxygen. Pulmonary veins carry the blood to the left side of the heart which pumps the blood through the aorta, the body's main artery. The arteries and capillaries transport the oxygen-rich blood through the body to the cells and tissues, and veins return the oxygen-poor blood to the heart. At rest, the heart pumps the entire blood volume (about 5 to 6 liters) every minute.

During space flight, the cardiovascular system changes its operation. Scientists have hypothesized that weightlessness affects this system when blood and other fluids move to the upper body and cause the heart to enlarge to handle increased blood flow. Pressure in the arteries rises and triggers baroreceptors (nerve cells clustered in the heart, the carotid artery in the neck, and the aorta), which signal the brain to adjust heart rate to maintain a consistent blood pressure. By mechanisms that are not well understood, the kidneys and the endocrine system reduce the quantity of fluids and electrolytes, leading to a reduction in total circulating blood volume.

The fluid shift appears to reach a maximum in 24 hours, and the heart reaches a new steady state of operation in 3 to 5 days. Previous experiments have detected some small changes that do not appear to impair cardiac function: decreased heart volume, increased blood volume in the upper body, head congestion, decreased blood volume in the lower body, decreased circulating blood volume, a small increase in resting heart rate, and a slight decrease in performance during strenuous exercise. None of these changes has affected crew productivity or resulted in an impairment of health.

Upon return to Earth, the cardiovascular system must readapt to Earth's gravity. When a person stands, gravity causes blood to pool in the lower part of the body. Before exposure to microgravity, the cardiovascular system can handle this without any problem, and blood pressure remains constant. After space flight, fluid shifts associated with standing challenge the cardiovascular system: the heart beats rapidly, but blood pressure often falls, and exercise capacity is reduced. The system usually returns to normal after a few days back on Earth. However, the exact mechanisms that cause the changes in cardiovascular function and the changes that might occur after long

flights remain unknown. SLS-1 experiments are the first to measure fluid distribution and cardiovascular adaptation over the course of an entire mission.

While some detailed studies of the cardiovascular system have been made, thorough studies of the lungs, which are very sensitive to gravity, have yet to be made. On Earth, gravity causes ventilation, blood flow, gas exchange, and pressure to vary in different regions of the lungs; scientists want to measure these parameters in microgravity. During space flight, astronauts have described small decreases in lung capacity; scientists speculate that these may be related to increases in blood volume in the upper body but need more precise measurements to verify this hypothesis.

The cardiovascular/cardiopulmonary system interacts with every organ in the body; thus, small changes in this system may propagate throughout the body. For this reason, six of the SLS-1 experiments focus on the heart, lungs, and blood vessels. Four experiments use crew members as subjects, and two experiments use rodents. These experiments record the most complete measurements ever made early in a mission when adaptation begins and continue through readaptation to 1-g. Extensive measurements are made of heart size, blood pressure, heart rate, blood volume, blood flow patterns, blood vessel characteristics, and lung functions. Images of the heart, blood vessel pressure measurements, and data from renal/endocrine system investigations make it possible to follow this system's adjustment as the body redistributes fluid.

Flight Experiments

A comprehensive investigation, **Cardiovascular Adaptation to Zero Gravity (Exp. No. 294)** developed by principal investigator Dr. C. Gunnar Blomqvist of the University of Texas Health Science Center, Dallas, Texas, tracks fluid redistribution and correlates it with changes in cardiovascular function, heart size, and cardiac response to exercise. This investigation records pictures of the heart, heart rate, blood pressure, central venous pressure, blood flow, and venous compliance.

One way to measure changes in the amount of fluid in the upper body is to measure changes in pressure in the large veins near the heart. As fluids shift toward the upper body, pressure in these veins increases; as upward fluid flow decreases, pressure equalizes. Before the mission, a cardiologist inserts a catheter (a thin, soft plastic tube) into the arm vein of each payload specialist and advances the tube to a point near the heart. The catheter is attached to monitoring systems on the outside of the body to measure and record pressure changes near the heart. Investigators can determine the degree and speed of fluid redistribution by noting corresponding changes in central venous pressure.

Above: In the middeck on Shuttle flight 51-D, Mission Specialist Dr. Rhea Seddon uses a sonar sensor to produce an image of Senator Jake Garn's heart on the echocardiograph screen. Crew members on SLS-1 use a similar technique to investigate the effects of microgravity on heart size and function.

Above right: The SLS-1 echocardiograph, installed in a Spacelab rack, shows a heart image.

The system records measurements for a total of 24 hours; by then, most of the fluid shift should have occurred and pressures should be stabilized. The payload specialist then removes the catheter. Soon after landing, a cardiologist inserts another catheter to measure central venous pressure changes associated with the return to Earth.

Another way of monitoring fluid shifts is to measure changes in blood pressure and blood flow in the leg. As fluids leave the lower body, legs may decrease in volume and blood flow to them may decrease. To check this hypothesis, venous compliance (the amount of blood in the leg for a given increase in leg vein pressure) is measured.

Throughout the mission, this investigation closely examines the heart to see how it adapts to weightlessness. A two-dimensional echocardiograph system uses high-frequency sound waves to produce real-time images of the heart. The sound waves strike various heart structures, which reflect the waves to a receiver where an image of the heart is displayed and recorded. An electrocardiogram (ECG), a measurement of cardiac rhythm and electrical activity, also is displayed to show at what point in heart activity the image was

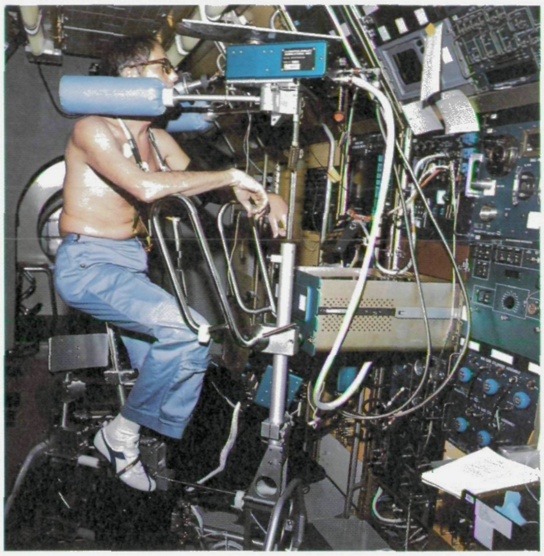
taken. Preliminary data from a simple echocardiograph flown on Shuttle mission 51-D revealed decreases in heart size for four crew members. This SLS-1 investigation looks for similar decreases and examines whether changes in heart volume are linked to reductions in heart performance.

The investigation, **Inflight Study of Cardiovascular Deconditioning (Exp. No. 066)** developed by Dr. Leon E. Farhi of the State University of New York, Buffalo, New York, focuses on the deconditioning of the heart and lungs and changes in cardiopulmonary function that occur upon return to Earth. By using noninvasive techniques of prolonged expiration and rebreathing, investigators can determine the amount of blood pumped out of the heart (cardiac output), the ease with which blood flows through all the vessels (total peripheral resistance), oxygen used and carbon dioxide released by the body, and lung function and volume changes.

Measurements are made while crew members are resting and while they ride an exercise bicycle. During the resting mode, the crew member sits on the bicycle without pedaling. For the exercise mode, the subject pedals the bicycle at different resistance levels that require various levels of exertion. With exercise, the heart rate, blood pressure, and metabolic demands of the body change. By comparing the results from tests before, during, and after the mission, investigators can tell if the condition of the heart changes and determine how this affects each crew member's ability to exercise.

The investigation, **Pulmonary Function During Weightlessness (Exp. No. 198)** developed by Dr. John B. West of the University of California at San Diego, La Jolla, California, is the first comprehensive assessment of human pulmonary function during space flight.

On Earth, gravity affects the way the lungs operate and may even exaggerate some lung disorders such as emphysema and tuberculosis. For example, gravity causes the distribution of ventilation (the air supply to the lungs) to be greatest near the bottom of each lung and become progressively smaller toward the top. In 1-g, the weight of both the rib cage and the lungs distorts the anatomy of the lungs. In microgravity, changes in lung anatomy may cause changes in lung performance. Investigators have hypothesized that during prolonged space flight, there may be changes in pulmonary ventilation, circulation, and gas exchange.



Astride the bicycle ergometer, SLS-1 Payload Specialist Dr. Robert Ward Phillips breathes quietly into the cardiovascular rebreathing unit during the resting phase of an experiment.

In a series of tests, the crew members measure pulmonary blood flow, lung diffusing capacity, and other functions. For each test, the subject breathes into a rebreathing assembly and manipulates two rotary valves to control the source of gas mixtures being breathed and to control the pathway of exhaled air.

As the subject inhales and exhales, a gas analyzer system identifies and determines the quantities of oxygen, carbon monoxide, carbon dioxide, nitrogen, argon, and nitrous

Training on the rebreathing assembly, Mission Specialist Dr. James Bagian inhales a predetermined gas composition. A gas analyzer mass spectrometer determines the composition of the gases he exhales. The rebreathing assembly and gas analyzer system are part of an investigation that explores how lung function is altered.

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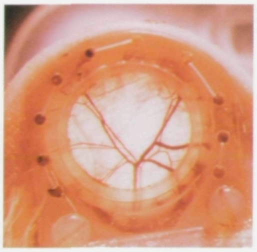
Payload Specialists Dr. Millie Hughes-Fulford and Dr. Robert Ward Phillips practice operations with the baroreflex neck pressure chamber, a collar that stimulates the baroreceptors in the carotid artery.



Microcirculatory chambers let scientists identify morphological changes that take place in the rat circulatory system. After the mission, investigators will examine the viewing chambers with microscopes to see whether new vessels have formed in response to weightlessness and associated fluid shifts. The growth of tiny new blood vessels may be related to increased cardiac output.

oxide, and the gas levels are displayed on a strip chart recorder along with an ECG. By comparing these test results with results from tests on Earth, investigators can determine the effects of microgravity on lung function. Other experiments that monitor cardiac responses augment this study, especially experiment 066 which also uses a rebreathing technique to study lung and heart functions during periods of rest and exercise.

The investigation, **Influence of Weightlessness Upon Human Autonomic Cardiovascular Control (Exp. No. 022)** developed by Dr. Dwain L. Eckberg of the McGuire Veterans Administration Medical Center and the Medical College of Virginia, Richmond, Virginia, focuses on postflight cardiovascular deconditioning, specifically the carotid baroreflex, which adjusts heart rate and blood pressure. The reflex is triggered by baroreceptors in the carotid artery.

On Earth, the force of gravity causes pressures inside the carotid artery and aorta to be different. Scientists have speculated that, in microgravity, headward fluid shifts equalize the pressure of these two areas and the baroreceptors become less responsive to changes in pressure during each arterial pulse. If weightlessness alters the baroreflex, this change may contribute to postflight deconditioning.

Normally when a person stands, blood rushes to the lower body, and the baroreflex increases heart rate and constricts blood vessels to maintain normal blood flow to the head; in space, blood no longer pools in the legs, so the baroreceptors do not have to make adjustments. Upon return to Earth, until heart rate and blood volume return to normal, crew members may experience falling blood pressure when they stand up and may feel faint (orthostatic intolerance). This may occur because the baroreflex no longer speeds the heart rate and constricts the blood vessels enough to maintain an adequate blood supply to the brain when a person stands.

To explore changes in the baroreflex during space flight and to study how it contributes to postflight deconditioning, the subject dons a neck chamber, a rubber cuff that extends from the chin to the collarbone, and a set of ECG electrodes. Pulses of pressure and suction applied through the neck chamber are sensed by the baroreceptors. The pulses mimic natural blood pressure changes but span a range greater than normally experienced by the baroreceptors. The pulses stimulate reflex changes in heart rate which the ECG records. When the cuff is slightly inflated, it compresses the carotid artery, which signals the brain that blood pressure is falling. When the neck collar applies suction, the opposite reaction occurs: the brain perceives that blood pressure is rising. Space-based measurements of the baroreflex can be compared to ground-based measurements to see if microgravity affects the reflex.

The experiment, **Cardiovascular Adaptation of White Rats to Decreased Gravity of Space Shuttle/Spacelab (Exp. No. 248)** developed by Dr. Vojin P. Popovic of Emory University Medical School, Atlanta, Georgia, identifies changes that take place throughout the rodent circulatory system. Cardiovascular measurements made before and after the mission and measurements taken from ground control rats determine changes in the venous pressure and blood flow. An ultrasound probe placed around each rodent's aorta measures changes in blood flow from the heart. Two pressure transducers connected to catheters in the carotid artery and the right side of the heart measure arterial and venous blood pressure. Regular postflight measurements chart cardiovascular readaptation to Earth's gravity. These results determine how suitable

rodents are as models of human cardiovascular changes associated with space flight and how closely changes induced in ground-based studies mimic those that occur as a result of space flight.

The second rodent cardiovascular experiment, **Correlation of Macro- and Microcirculatory Alterations During Weightlessness (Exp. No. 166)** developed by Dr. Phillip M. Hutchins of Bowman Gray School of Medicine, Winston-Salem, North Carolina, uses the same test subjects as experiment 248 to correlate circulatory alterations caused by weightlessness with blood pressure and flow changes. Similar changes may be involved in cardiovascular deconditioning and orthostatic intolerance in humans.

Scientists have hypothesized that the vigor and number of blood vessels may change as a result of the extra blood flow caused by fluid redistribution in microgravity. Doctors have observed that some hypertensive patients who suffer from an elevated cardiac output have a reduced number of tiny arteries (arterioles) and an increased number of small veins (venules). If the mechanisms leading to cardiovascular deconditioning during weightlessness and the mechanisms leading to hypertension are similar, an increased number of venules may develop during space flight, and these will have poor vascular tone.

Upon return to Earth, the shift in blood pressure produced by gravity may not be countered by constriction of the veins in the lower body regions, which could account for orthostatic intolerance. A change in the ratio of arterioles to venules would also favor fluid reabsorption into the veins, elevating the amount of blood returning to the heart, which is already increased by the headward fluid shift that occurs upon entry into weightlessness. A microcirculatory chamber, a one-centimeter viewing area implanted on the surface of each animal's skin, allows scientists to look at rodent blood vessels under a microscope and note changes in blood vessel morphology or any new blood vessels that have formed, a procedure that is impractical to perform on people. These activities will provide baseline information to develop inflight measurements for future experiments. ■

Cardiovascular/Cardiopulmonary System Investigator Teams

EXPERIMENT NO. 294

Principal Investigator:

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Co-Investigators:

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Dr. F.A. Gaffney (SLS-1 Payload Specialist)
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Dallas, Texas

EXPERIMENT NO. 066

Principal Investigator:

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Co-Investigators:

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Dr. M.A. Rokitka
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EXPERIMENT NO. 198

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Co-Investigators:

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Dr. G.K. Prisk
Dr. P.D. Wagner
University of California at San Diego
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Richmond, Virginia

Co-Investigator:

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EXPERIMENT NO. 166

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Co-Investigator:

Dr. T.L. Smith
Bowman Gray School of Medicine
Winston-Salem, North Carolina


CHANGES IN
Percent change
0
-1
-2
-3
-4
-5
3
5
7
Mission Days
NASA

The Renal/Endocrine System: Kidneys and Hormone-Secreting Organs

The kidneys and the many hormone-secreting organs and glands (such as the adrenals, pituitary, and thyroid) are part of the body's regulatory system. The kidneys control water balance and the removal of waste products and help regulate blood volume and pressure. Hormones are secreted throughout the body to control various functions, such as growth and blood pressure. These chemical messengers may initiate a response in one organ or may coordinate activities between systems.

Just as a thermostat keeps a room at a set temperature, the kidneys and hormones keep the body in a stable state with the right amount of fluids and electrolytes (dissolved salts and minerals such as sodium, potassium, calcium, and phosphate). One of the main functions of the kidneys and hormones is to regulate blood volume. If sensors in the circulatory system detect too much or too little fluid, the brain and heart signal the glands and kidneys to secrete specific hormones that either reduce or increase body fluids.

Responses to weightlessness by the renal/endocrine system may be closely related to cardiovascular responses. Experiment results suggest that as microgravity causes fluid to migrate toward the head, the cardiovascular system perceives an increase in blood volume, and the renal/endocrine system reacts by removing fluids and electrolytes. Since scientists have studied so few test subjects, they do not know the mechanisms that mediate changes in fluid and electrolyte balance. In addition, astronauts may experience space motion sickness, which compounds the problem by decreasing their desire to eat and drink.

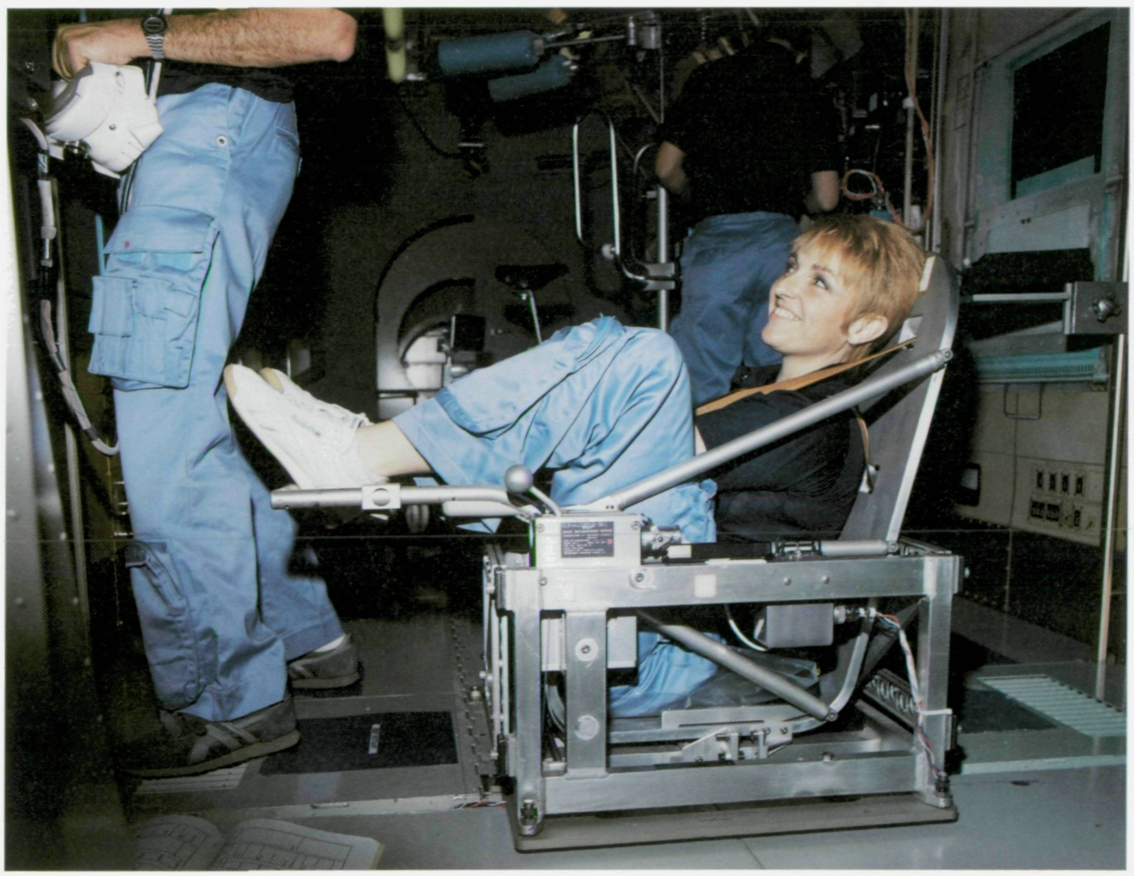
The effect of microgravity on the body's regulation of hormone concentrations is unclear. There is evidence that hormone secretion is altered, but related effects on the kidneys, blood vessels, and heart have not been studied. An understanding of this relationship may shed light on diseases such as high blood pressure and heart failure as well as space flight deconditioning.

Changes in the renal/endocrine system appear to occur in two phases: an acute phase, lasting from hours to days, and an adaptive phase, lasting from days to weeks. A significant reduction in body fluids and electrolytes characterizes the acute phase; the adaptive phase is the period of adjustment to the new fluid volumes and compositions.

SLS-1 investigations collect data early in flight when rapid changes are expected to occur in kidney function and hormone levels. Before this mission, scientists used ground-based simulations to develop hypotheses about what happens to the body during the first hours in space. Subjects immersed in water, confined to bed, or resting in a head-down position appear to have some of the same physiological changes as space travelers; all experience a rapid headward shift of fluids that initiates a complex set of reactions, including pressure increases in the blood vessels, enhanced renal blood flow, altered hormone secretion, increased excretion of fluids and electrolytes, and diminished thirst and water intake.

Because few measurements have been made during the initial hours of missions, ground-based models have not been validated. For instance, samples collected every 24 hours during Skylab did not show expected increases in renal excretions of salt and urine, leading scientists to postulate that dehydration might be responsible for the fluid reductions; however, measurements may not have been taken soon enough to detect the increases. During SLS-1, samples are taken every time a crew member voids so that scientists can identify any early changes in fluid balance.

Weight is a function of gravitational force on mass, and in space only measurements of mass can be made. Payload Specialist Dr. Millie Hughes-Fulford sits strapped in the special device scientists have developed for determining mass on orbit. As the chair swings back and forth, a timer records how much the crew member's mass retards the chair's movement.



The Urine Monitoring System, which is connected to the Shuttle waste management system in the middeck, can measure urine volume and collect samples each time a subject voids. The samples are stored for postflight analysis.

Flight Experiment

The investigation, **Fluid-Electrolyte Regulation During Space Flight (Exp. No. 192)** developed by Dr. Carolyn S. Leach of the NASA Johnson Space Center, Houston, Texas, measures fluid shifts immediately from the onset of weightlessness and seeks to determine if the human renal and circulatory systems conform to hypotheses formulated in ground-based studies that simulate low-gravity. The experiment identifies immediate and adaptive changes in kidney function, changes in water, salt, and mineral balances, shifts in body fluids from cells and tissues, and changes in hormone levels that affect the kidneys and circulation. Data from the experiment are correlated with data from the cardiovascular experiments to determine how the responses of the systems are related.

Crew members give urine and blood samples as soon as possible in flight and at specified intervals thereafter; the samples are stored and returned for analysis. Body mass is measured daily, and a log is kept of fluids and medications consumed by each crew member; the dietary log helps monitor ingestion of sodium, potassium, calcium, and protein.

Early in the flight, the subjects are injected with chemical tracers that are distributed in the blood. Renal clearance tests (which determine the amount of certain tracers released from a given volume of blood or plasma into the urine in a specified time) help scientists follow the fluid shift and spot changes in kidney function and water, salt, and mineral balances. These tests are done twice in flight by collecting blood samples at timed intervals after each subject has received a carefully measured dose of tracers.

To determine the amount and rate of body water loss, each subject drinks water containing a heavy isotope of oxygen; then urine samples are collected at timed intervals to measure losses of this water. By collecting blood samples at timed intervals after the water is drunk, scientists can measure plasma volume and extracellular fluid volume.

Sensitive assays of both blood plasma and urine collected during SLS-1 are performed after the mission to reveal changes in hormones, such as aldosterone, antidiuretic hormone, angiotensin I, prostaglandins, cortisol, and adrenocorticotropin, which regulate fluid and electrolyte levels in the body.

Before and after flight, crew members participate in the same experiments, and simultaneous ground experiments are done with non-crew subjects to determine the changes resulting from space flight. ■

Renal/Endocrine System Investigator Team

EXPERIMENT NO. 192

Principal Investigator:

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Houston, Texas

Co-Investigators:

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Houston, Texas

Dr. J.I. Leonard
Lockheed Engineering and Sciences
Washington, D.C.

Dr. P.C. Rambaut
National Institutes of Health
Bethesda, Maryland

The Blood System: Blood Plasma and Red Blood Cells

Red blood cell magnified by a scanning electron microscope

SLS-1 hematology investigations study two parts of the blood system: a liquid portion called plasma, which contains water, proteins, nutrients, electrolytes, hormones, and metabolic wastes, and a cellular portion, which includes red blood cells and platelets.

Plasma constitutes more than half of blood volume. By analyzing plasma, investigators can find out what types of nutrients are circulating throughout the body and determine whether an astronaut is well-hydrated. They can measure the levels of hormones and other constituents that plasma transports.

In a pinhead-size drop of blood, there are some 5 million red blood cells. These cells, also known as erythrocytes, transport oxygen throughout the body. Previous space flight studies have shown consistent reductions in the circulating red cell mass and blood plasma volume of crew members. Scientists postulate that when microgravity causes fluid to move toward the head, the body perceives an increase in fluid and reduces body liquids such as blood plasma. This results in an increased proportion of solids, such as cells, to plasma in the blood. Thus, the body may try to reduce what it perceives as too many erythrocytes. A decrease in red blood cells may impair a crew member's ability to function with full efficiency upon return to Earth.

While red blood cell loss has been clinically insignificant, doctors consider it a potentially adverse response that may require control during inflight illness or injury, repeated space flights, and long-duration missions. If the body adjusts to microgravity and produces a normal quantity of blood cells, there may be no problem created by lengthy stays in space; however, if the reduction grows more severe with longer space trips, investigators will have to determine why.

From limited data gathered in space and ground-based studies, scientists suggest two theories to explain this "space anemia." First, they hypothesize that the body may limit erythrocyte production by suppressing erythropoietin, a hormone that stimulates red blood cell production in the bone marrow. A second theory postulates that red cell production may remain unchanged but that the body destroys erythrocytes faster than it creates them, thus decreasing their numbers. Other aspects of adaptation, such as altered nutrition and bone loss, also may influence red blood cell counts. To date, not enough data exist to confirm or refute these theories.

Previous space studies have provided only limited inflight blood analysis and have not included extensive measurements of red blood cell parameters. Three SLS-1 investigations examine the mechanisms that may contribute to erythrocyte loss. One experiment studies human responses, while two others use rodents as subjects. This is the first time that scientists have studied the blood characteristics of rodents so extensively with regard to space flight. To qualify the rat as a suitable hematologic model for humans, data from these investigations will be compared with those from similar tests done on human blood samples. All three experiments make inflight and postflight measurements of blood volume, hormones, and other blood constituents to see if and how red blood cell production is suppressed. Results from the renal/endocrine experiment will help hematologists interpret data by measuring several factors that influence red blood cell population size.

Flight Experiments

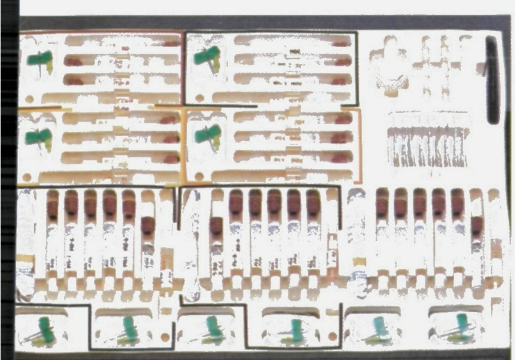
Dr. Clarence P. Alfrey of the Baylor College of Medicine and Methodist Hospital, Houston, Texas, is the principal investigator for the investigation, **The Influence of Space Flight on Erythrokinetics in Man (Exp. No. 261)**, which measures red blood cell mass and plasma volume in humans and studies the role of specific mechanisms (such as decreased erythropoietin production) that might lead to decreased red cell production.

Four crew members are injected with tracers that can be used to determine certain characteristics of the blood. Iodine attaches to human albumin and allows total circulating plasma volume to be measured; chromium attaches to red blood cells, allowing red blood cell mass and survival to be measured. Iron travels to the bone marrow where red blood cells are produced; blood samples taken at timed intervals show the rate at which the red blood cells incorporate iron.

At specified times during the mission, blood samples are taken and processed in a centrifuge to separate plasma from cellular components. Postflight assays reveal red blood cell counts, erythropoietin level, plasma volume, and other related parameters. The same measurements are made on blood samples obtained before and after the flight. Non-crew subjects serve as controls to isolate changes that occur as a result of space flight from changes induced by other factors, such as the blood sampling procedure.

In the **Regulation of Blood Volume During Space Flight (Exp. No. 141)** experiment, for which Dr. Alfrey is also the principal investigator, rodents are injected with the same tracers as the human subjects, and blood samples are analyzed before flight for plasma volume, red blood cell mass, number of new red blood cells produced, and rate of red blood cell removal. These data are compared with identical measurements from blood samples taken after the flight.

The second rodent experiment, **Regulation of Erythropoiesis in Rats During Space Flight (Exp. No. 012)** developed by Dr. Robert D. Lange of the University of Tennessee Medical Center, Knoxville, Tennessee, examines parameters of hematopoiesis (the formation of blood cells), factors known to affect cell production (such as erythropoietin levels and bone marrow cell sensitivity to erythropoietin), and the animals' nutritional states. The rodents studied in experiment 141 are also test subjects in this investigation. Blood samples are analyzed before and after the mission for total cell counts; morphological changes in cells of the peripheral blood, bone marrow, and spleen; lymphocyte subsets; reticulocyte counts; and changes in erythropoietin levels and cellular responses to erythropoietin. ■



One day's blood collection equipment, color coded for each crew member, is neatly organized in a kit.

Blood samples from crew members are critical to several SLS-1 investigations. Payload Specialists Dr. Millie Hughes-Fulford and Dr. Drew Gaffney practice blood draw procedures.

Blood System Investigator Teams

EXPERIMENT NO. 261

Principal Investigator:

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Co-Investigator:

Dr. C.S. Leach
NASA Johnson Space Center
Houston, Texas

EXPERIMENT NO. 141

Principal Investigator:

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and Methodist Hospital
Houston, Texas

Co-Investigators:

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Dr. R.G. Nachtman
NASA Johnson Space Center
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EXPERIMENT NO. 012

Principal Investigator:

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Co-Investigators:

Dr. J.B. Jones
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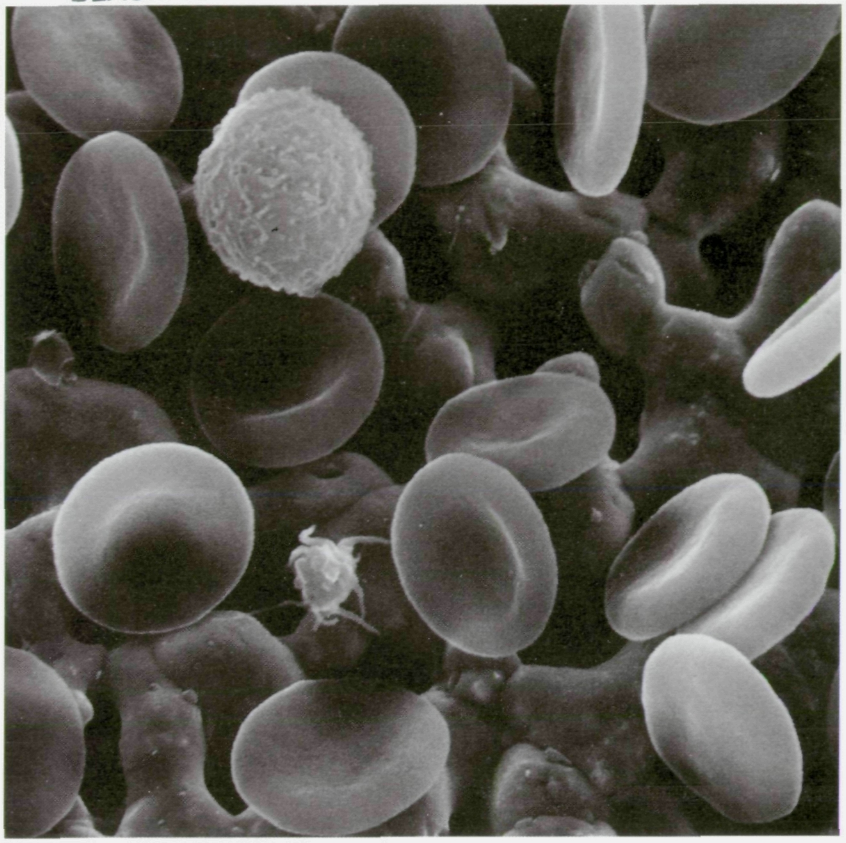
Athens, Georgia

Dr. R.E. Worthington
University of Tennessee
Medical Center
Knoxville, Tennessee

The Immune System: White Blood Cells



White blood cells, red blood cells, and a platelet magnified by a scanning electron microscope

The immunology investigation examines lymphocytes, one kind of white blood cell that helps the body resist infection. These cells recognize harmful foreign substances, such as bacteria, and eliminate them.

Analyses of lymphocytes from crew members on the first 12 Shuttle flights revealed decreases in the number of circulating lymphocytes; postflight results showed that the lymphocytes were not as effective in responding to challenges. However, astronauts have shown no increased susceptibility to disease, and white blood cell counts return to normal a few weeks after landing. Still, these changes in the immune system must be understood and controlled because they could have undesirable consequences on longer missions.

Space flight may reduce white blood cell counts and effectiveness either because microgravity causes a decrease in lymphocyte production or because the stress of space flight alters cell counts or function. (Studies on Earth strongly suggest that the body's lymphocyte count is lower during periods of increased stress.) Researchers have conducted most previous immunology studies pre- and postflight, but it has been difficult to separate the direct effects of microgravity from the indirect effects resulting from the stress of postflight recovery.

An experiment flown on Spacelab 1 contributed substantially to understanding the immune system's operation in space. Lymphocytes go through a process called activation in which they identify a foreign substance, produce the appropriate antibody, and proliferate to make sufficient amounts of the antibody. Lymphocyte cultures flown on the Spacelab 1 mission lost almost all ability to respond to foreign challenge. Proliferation of the flight lymphocytes was less than 3 percent of that for ground-control lymphocytes. Although the cells were alive, they did not respond to the stimulus. The experiment was repeated on Spacelab D1 with cultures exposed to microgravity, cultures on a 1-g centrifuge, and blood taken from the crew members during the mission. Cultures on the centrifuge, which simulates gravity, were important because factors other than microgravity (such as radiation) were candidates for altering the cells' response. The Spacelab 1 results were confirmed: cell activation in the cultures exposed to microgravity was depressed when compared with control cultures on the flight centrifuge and on the ground.

Activation of lymphocytes in the crew blood samples was markedly depressed in samples taken in flight as well as in samples drawn 1 hour after landing; the activation process in crew members' white blood cells did not fully return to normal until 1 to 2 weeks after landing. The next step is to discover which stage of the activation process is affected, to postulate a mechanism for the change, and to determine whether the effect can be prevented.

Flight Experiment

The immunology investigation, **Lymphocyte Proliferation in Weightlessness (Exp. No. 240)** developed by Dr. Augusto Cogoli of the Institute of Biotechnology, Gruppe Weltraum Biologie, Zurich, Switzerland, continues previous Spacelab experiments by examining the effects of weightlessness on lymphocyte activation.

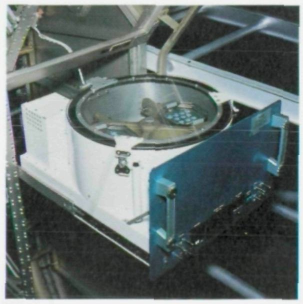
Lymphocytes purified from human blood collected 12 hours before launch are suspended in a culture medium and stored in an incubator in the Shuttle middeck. During the first day of the mission, a crew member transfers the incubator to Spacelab. As soon as possible, the cell cultures are injected with a mitogen (a substance that promotes cell division) called concanavalin A. The cells' ability to proliferate is determined by injecting them with a chemical isotope tracer for an appropriate period before they are preserved (fixed) for postflight analysis. This tracer, tritiated thymidine, attaches to the cells' genetic material (DNA). As the cells divide, newly formed cells will incorporate the tracer into their DNA. At specified times, the cells are sampled and fixed; some cells are allowed to grow for 3 days. On the ground, investigators compare the cultures preserved at different times to see if the length of exposure to microgravity influences cell activation. The lymphocyte cultures also will be compared with lymphocytes from crew blood samples.

Blood samples drawn from the crew are put in a culture with concanavalin A and exposed to varying gravity levels on a centrifuge. After 3 days, these samples are labeled, incubated for an appropriate time, and fixed for postflight study. By comparing the samples, the investigator can determine if weightlessness depresses lymphocyte proliferation and high-gravity enhances it.

Investigators analyze all the samples postflight. Electron microscopy is used to compare flight samples with control cultures grown on Earth during the mission. ■

Data suggest that weightlessness affects the activation of white blood cells. These lymphocytes, cultured at 1-g in the centrifuge on Spacelab D1, reproduced and manufactured antigens when mitogens were introduced into the medium. Lymphocytes grown under microgravity conditions degenerated, did not proliferate, and did not produce antigens.

Lymphocyte cultures are grown in microgravity in incubators (left). Blood samples, taken in flight from the crew, are placed in a low-gravity centrifuge (below), which simulates several gravity levels (0.5-g, 1.0-g, 1.5-g, and 2.0-g), fixed for postflight analysis, and transferred to a freezer.



Immune System Investigator Team

EXPERIMENT NO. 240

Principal Investigator:

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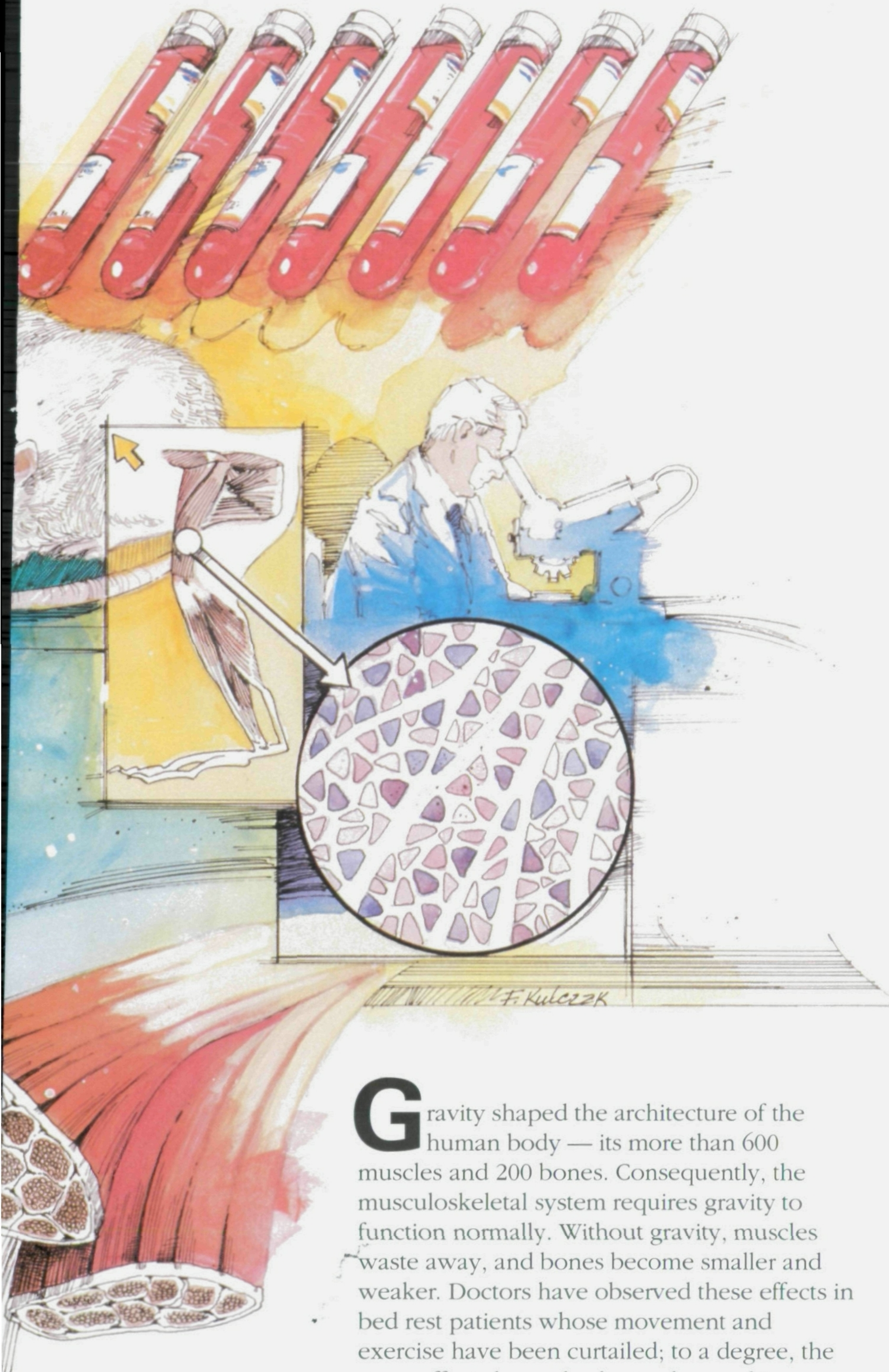
Gruppe Weltraum Biologie
Zurich, Switzerland

Co-Investigator:

Dr. B.S. Criswell
University of Arizona
Tucson, Arizona


mg/24h.
Flight Days
CALCIUM BALANCE AS
A FUNCTION OF
FLIGHT DAYS

The Musculoskeletal System: Muscles and Bones

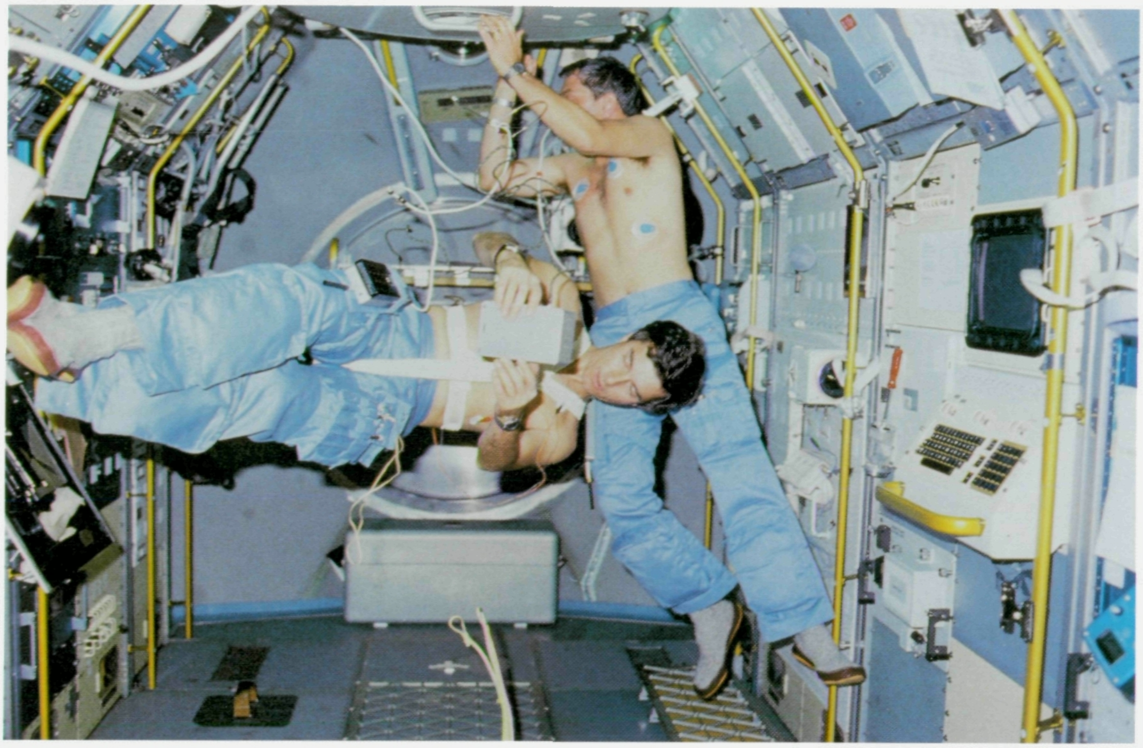


Gravity shaped the architecture of the human body — its more than 600 muscles and 200 bones. Consequently, the musculoskeletal system requires gravity to function normally. Without gravity, muscles waste away, and bones become smaller and weaker. Doctors have observed these effects in bed rest patients whose movement and exercise have been curtailed; to a degree, the same effects have also been observed in space flight crews.

In microgravity, leg muscles often become weakened from lack of use because astronauts can "float" instead of walk. Specific changes include a loss of nitrogen from the muscle, loss of lower body mass, reduced muscle mass in the calves, and decreased muscle strength. These changes may occur through a decrease in protein synthesis or an increase in protein breakdown or both. What biochemical mechanism communicates the message to slow down protein synthesis or speed up protein destruction? Answers to this question will impact muscle research on Earth as well as in space.

Rodent experiments on Spacelab 3 permitted researchers to observe and document fundamental changes in muscles exposed to weightlessness. Rodents flown in space for 7 days lost 40 percent of mass in the leg muscles that are normally used to oppose gravity. Related findings include almost total absence of muscle tone and a marked decrease in the diameters of muscle fibers. In addition, the biochemical process that generates energy in muscle cells was almost totally absent. Detailed tissue analyses from flight rodents confirmed the hypothesis that microgravity exposure results in a decrease of muscle fibers used to maintain an upright position in gravity and an increase in fibers used for rapid, active exercise.

Human studies during the longer Skylab missions showed that the most significant muscle losses occurred during the first months of flight. Exercise on a treadmill and a stationary bicycle appeared to inhibit muscle and nitrogen loss but did not curtail it completely. Muscle fatigue contributes to postflight complications, creating a temporarily reduced state of physical fitness. Full recovery of muscular strength takes from weeks to months, depending on the duration of the flight.



In space, crew members move about without walking. Leg and skeletal muscles that act against gravity on Earth degenerate in microgravity because they are not stimulated or stressed.

Weightlessness also causes a slow loss of bone minerals (calcium and phosphorus). Crew members from previous flights have shown a negative calcium balance throughout the missions. Most of the loss is thought to occur in the leg bones and the spine which are responsible for erect posture and locomotion. Rodents flown on the Spacelab 3 mission exhibited some interesting changes in bone: decreased skeletal growth early in the mission; reduced concentrations of a protein (osteocalcin) that bone-forming cells secrete, suggesting a reduction in the activity of these cells; and reduced leg strength and bone mass in the spine indicating that animal bones become significantly more fragile after even brief exposure to microgravity.

So far, investigators do not know whether the body would continue to lose calcium indefinitely or whether the loss would stop at a certain point. To date, exercise regimens have not halted skeletal wasting or reduced calcium loss. Some previous studies indicate that diet may be a potential aid in calcium regulation.

An understanding of the time course and extent of muscle and bone alterations is critical to determining how long humans may safely remain in space and what can be done to halt negative effects. Development of effective countermeasures to bone loss in space may contribute to improved therapy or management of osteoporosis, which is characterized by gradually decreasing bone mass and strength and is the most prevalent clinical bone disorder on Earth.

Six SLS-1 experiments study the mechanisms responsible for muscle and bone loss in humans and rodents. These experiments will further determine which muscles are affected and what biochemical mechanisms are responsible for altering the nitrogen balance of muscles and the calcium balance of bones.

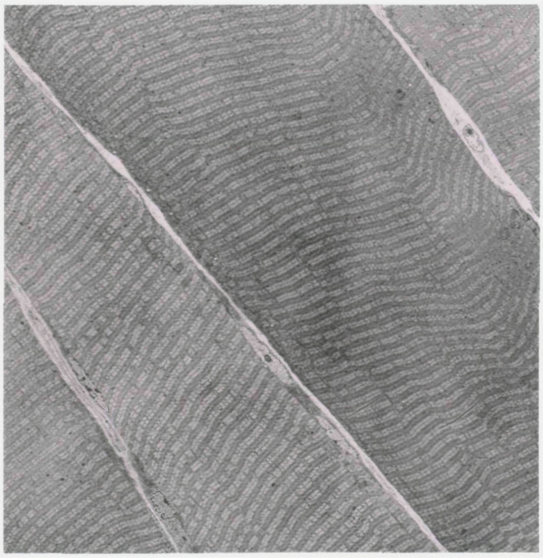
Muscle Flight Experiments

One experiment, **Protein Metabolism During Space Flight (Exp. No. 120)** developed by Dr. T. Peter Stein of the University of Medicine and Dentistry of New Jersey, Camden, New Jersey, examines the mechanisms involved in the altered protein metabolism by measuring protein synthesis and breakdown rates.

Subjects ingest ^{15}N glycine, an amino acid labeled with a nonradioactive isotope of nitrogen. By labeling amino acids, which are the primary building blocks of proteins, scientists can trace protein metabolism in the body. By measuring the nitrogen isotope in blood and urine samples, investigators calculate how much protein is being made and broken down.

Crew members give blood and urine samples after glycine ingestion and prepare and freeze the samples for postflight analyses. Researchers also measure nitrogen balance; urinary 3-methyl histidine, a marker for muscle protein breakdown; and urinary hydroxyproline and hydroxylysine excretion, indicators of connective tissue breakdown. The rate of synthesis of several blood proteins, including fibrinogen, albumin, immunoglobulin-g, and hemoglobin, are calculated from the amount of labeled amino acid incorporated into the respective proteins.

Another investigation, the **Effects of Zero-Gravity on Biochemical and Metabolic Properties of Skeletal Muscle in Rats (Exp. No. 127)** developed by Dr. Kenneth M. Baldwin of the University of California Collegè of Medicine at Irvine, Irvine, California, uses rodents to explore the following hypothesis: in low-gravity, tension is reduced on muscles that support the body against gravity, resulting in a loss of muscle mass and an accompanying loss of muscle strength. On Earth, the stress on these muscles maintains adequate concentrations of proteins and enzymes that enable muscle cells to use oxygen to convert nutrients into energy. When stress is reduced, protein activity also decreases, and muscles become more dependent on glycogen for energy. As the body metabolizes glycogen, muscle endurance decreases.



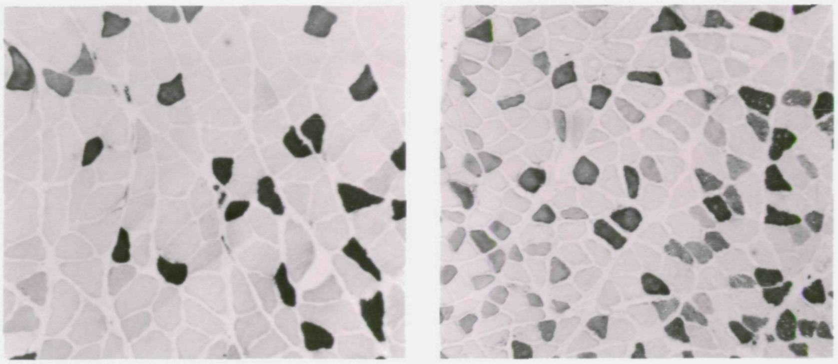
To test this hypothesis, scientists use radioactive carbon compounds to evaluate energy metabolism in the back leg muscles of rats exposed to space flight. The concentration of the enzymes reflects the kind of metabolic activity occurring in muscles during periods of reduced gravitational stress. In a complementary analysis, the skeletal muscle cells of the flight rats are compared with those from ground control rats to assess any changes in the concentration of enzymes that break down glycogen.

The progressive atrophy of certain muscles in microgravity is the focus of an experiment developed by Dr. Dan A. Riley of the Medical College of Wisconsin, Milwaukee, Wisconsin. This investigation, **Effects of Microgravity on the Electron Microscopy, Histochemistry, and Protease Activities of Rat Hindlimb Muscle (Exp. No. 303)**, compares the atrophy rates of muscles used primarily to oppose gravity and those muscles used for movement.

Postflight, investigators examine the muscle tissues of flight and ground control rats with light and electron microscopes for evidence of the shrinkage or death of muscle cells, breakdown of muscle fibers, or degeneration of motor nerves. Scientists also hope to discover the chemical basis for atrophy by analyzing the concentration of proteases, the enzymes that catalyze the breakdown of proteins within cells.

A second emphasis of this study is the trauma that motor nerves and neuromuscular junctions undergo during space flight. Researchers scrutinize the tissues for physical and chemical changes that may be related to the stress of launch, low-gravity, reentry, and readaptation to Earth's gravity. By defining how several factors contribute to the muscle weakening, effective countermeasures can be developed to overcome atrophy during space flight.

Electron micrographs of flight rodent tissues are analyzed for evidence of muscle atrophy.



These light micrographs show the effect of microgravity on the size and kind of muscle cells in the leg muscles of rats. The larger cells (left) are from a ground control rat; the smaller cells (right) are from a Spacelab 3 rodent. The dark-stained fast-twitch muscle fibers are more numerous in the flight animal.

Another musculoskeletal investigation, **Skeletal Myosin Isoenzymes in Rats Exposed to Zero Gravity (Exp. No. 247)**, has been designed by Dr. Joseph Foon Yoong Hoh of the University of Sydney, Sydney, Australia. This study determines how microgravity affects the speed of muscle contractions. Skeletal muscle fibers are classified as either slow or fast twitch, depending on how fast they contract, and this characteristic is directly related to the amount of the protein myosin in muscle fibers. Myosin is made up of five isoenzymes of varying structures and functions, and the firing of motor nerves regulates its synthesis. In 1-g, a low-firing frequency stimulates the slow-twitch fibers, which support a body against gravity; the fast-twitch fibers (related to body movement) contract in response to high-frequency nerve impulses. Because stimuli to the slow-twitch, antigravity muscles should be greatly reduced in low-gravity, the concentration of myosin isoenzymes in these fibers should be lower. Investigators analyze slow-twitch muscle fibers from the rats' hind legs to determine the biochemical makeup of the tissues.

Bone Flight Experiments

The investigation, **Pathophysiology of Mineral Loss During Space Flight (Exp. No. 305)** developed by Dr. Claude D. Arnaud of the Veterans Administration Hospital, San Francisco, California, examines changes in the balance of calcium entering and leaving the body. Abnormalities in calcium balance observed during space flight are similar to those seen in patients with osteoporosis, a condition in which bone mass decreases and bones become porous, brittle, and prone to fracture. The objective is to measure changes in circulating levels of calcium hormones and directly measure the uptake and release of calcium in the body.

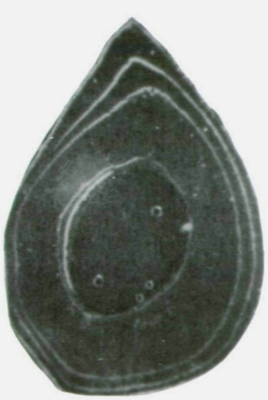
Although previous space flight experiments have shown an increased loss of calcium, they have not measured the levels of hormones and metabolites responsible for stimulating bone-producing cells using calcium. There may be significant changes in the amount of these hormones caused by an increase in the breakdown and reassimilation of bone tissue (resorption), changes that begin within hours after entering the weightless environment. For the first time, biochemicals such as parathyroid hormones, calcitonin, and the vitamin D metabolites are measured in blood and urine samples from crew members.

An investigation that closely parallels the human experiment is **Bone, Calcium, and Space Flight (Exp. No. 194)** developed by Dr. Emily M. Holton of the NASA Ames Research Center, Moffett Field, California. It uses young white rats in a rapid growth stage to document alterations in bone growth patterns and strength in rodents exposed to weightlessness and to determine whether bone formation returns to normal levels after space flight.

This experiment focuses on growth that occurs in a number of specific rat bones such as the leg, spine, and jaw bones. To determine if microgravity inhibits bone development or causes bone loss, each rat is injected preflight with a fluorescent bone marker that becomes visible when the bone is placed under ultraviolet light. Bone formed during the mission should not contain the fluorescent label; thus, investigators can measure the rate of bone development that occurred during flight.

After the mission, some rats receive radioactive proline, an amino acid necessary for bone development. Investigators can determine the rate of new bone formation after flight from images produced on photographic emulsions by the radioactive emissions from the rats' tissues. Ground-control rodents undergo similar procedures. ■

The pattern of rat bone growth that occurs after space flight is marked by fluorescent tracers.



Musculoskeletal System Investigator Teams

EXP. NO. 120

Principal Investigator:

Dr. T.P. Stein
University of Medicine and Dentistry of New Jersey
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Co-Investigator:

Dr. R.G. Settle
Philadelphia Veterans Administration Hospital
Philadelphia, Pennsylvania

EXP. NO. 127

Principal Investigator:

Dr. K.M. Baldwin
University of California College of Medicine at Irvine
Irvine, California

EXP. NO. 303

Principal Investigator:

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Medical College of Wisconsin
Milwaukee, Wisconsin

Co-Investigators:

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San Jose State University
San Jose, California

Dr. A. Haas
Medical College of Wisconsin
Milwaukee, Wisconsin

EXP. NO. 247

Principal Investigator:

Dr. J.F.Y. Hoh
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Sydney, Australia

EXP. NO. 305

Principal Investigator:

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Co-Investigators:

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Dr. B.P. Halloran
Veterans Administration Hospital
San Francisco, California

EXP. NO. 194

Principal Investigator:

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Dr. A.C. Vailas
University of Wisconsin
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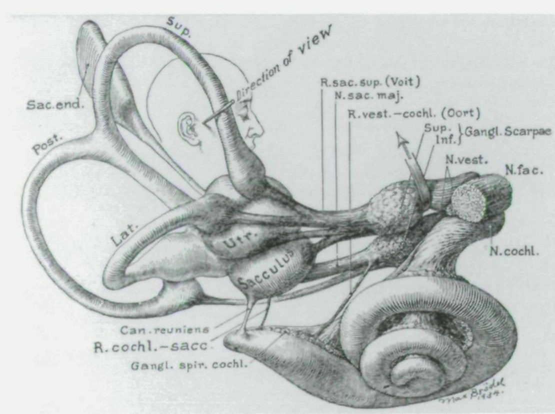
Human otoliths

The Neurovestibular System: Brain and Nerves, Eyes, and Inner Ear

Just as aircraft and spacecraft maintain their positions based on information from radar, gyroscopes, accelerometers, and other sensors, human beings rely on several neural orientation sensors. These sensors send out nerve impulses that are integrated and interpreted by the brain.

The neurovestibular system, which helps people orient their bodies, is very sensitive to gravity. For instance, the otoliths, small vestibular organs in the inner ear, respond to the acceleration of an elevator. As a person changes positions, gravity pulls tiny clumps of crystals down and bends hairs in the inner ear; then the more than 20,000 nerve cells in each ear tell the brain the head's position. Nerves also constantly perceive gravity as muscles relax and contract and use this information to sense body position. The eyes see surroundings and sense the body's relationship to other objects.

In space, gravity no longer tugs at the otolith crystals, and the muscles no longer have to support the weight of the limbs. Theory suggests that, in microgravity, information sent to the brain from the inner ear and other sense organs conflicts with cues anticipated from past experience in Earth's 1-g environment. This conflict results in disorientation.



Semicircular canals and otoliths in the inner ear detect acceleration and gravity. Messages to the brain from the inner ear, special muscle cells, and the eyes are critical for determining spatial orientation and position.

Neurosensory research in space has focused on space motion sickness because changes in neurovestibular activity may cause this ailment, which has affected about one-half of all space travelers. Symptoms may include pallor, loss of appetite, nausea, and vomiting. Although the symptoms are similar to Earth motion sickness, scientists are unsure if the stimulus is the same since crew members who are susceptible to Earth motion sickness may not experience space motion sickness and vice versa. There are no tests that predict which individuals will experience discomfort or to what degree.

The body adapts quickly: the most severe symptoms occur during the first days of flight and disappear after a few days. However, NASA wants to improve crew efficiency and comfort by eliminating space sickness. Although astronauts have used some drugs successfully to reduce nausea, no treatment expels the symptoms. Experiments have focused on identifying the underlying causes of this problem and ways to treat it and on studying how the nervous system adapts to microgravity.

During the Spacelab 1 and D1 missions, a group of complementary experiments sponsored by American, Canadian, and European scientists studied how the sensory system adapts to weightlessness. Research examined the interrelated functioning of the inner ear, the eyes, and the reflexes. Crew members reported that head movements as well as visual disorientation provoked space motion sickness. Posture disturbances and modified reflex activity in the muscles also were recorded. These results and others seemed to fit the sensory conflict theory.

Investigators are repeating several of these experiments on SLS-1. Signs and symptoms of space motion sickness are measured, and human spatial orientation and posture control are measured during the course of adaptation to microgravity. Experiments with rodents and jellyfish examine the structure of gravity-sensitive organs to see if weightlessness causes any anatomical changes to vestibular organs.

Flight Experiments

A team led by Dr. Laurence R. Young of the Massachusetts Institute of Technology, Cambridge, Massachusetts, developed one set of investigations, **Vestibular Experiments in Spacelab (Exp. No. 072)**, that studies the interaction among the otoliths, semicircular canals, vision, and spinal reflexes in humans. The main objective is to determine how the body, which receives redundant information from several sensory sources, interprets this information in microgravity. Another objective is to record and characterize the symptoms of space sickness experienced by crew members.

Crew members wear accelerometers and tape recorders that measure head movements. If they experience space sickness, they record the symptoms and the time of occurrence. By comparing accelerometer data and reports of symptoms, investigators can study the relationship between provocative head movements and periods of discomfort.

The role of visual cues in causing space sickness also will be studied. The subjects test a collar that restricts head movements to see if wearing it reduces the occurrence of space sickness symptoms. To complement flight data, crew members participate in motion

Spacelab 1 Payload Specialist Dr. Byron Lichtenberg wears a cassette data tape recorder and head accelerometer similar to those that SLS-1 crew members wear. Head movements sensed by the accelerometer are recorded.

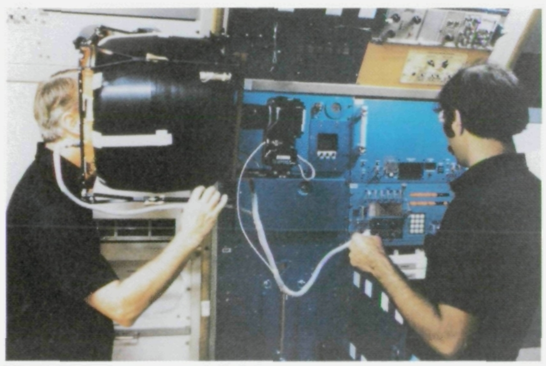
sickness susceptibility tests before and after the mission. Investigators want to see if tests on the ground and in aircraft that complete parabolic flight patterns simulating low-gravity for a few minutes can help them predict whether sickness will occur in orbit.

When a person rotates the head, the eyes must rotate in the opposite direction to remain fixed on an object long enough to obtain a clear image. After the eyes have rotated to one side, they jump suddenly in the direction of head rotation to fix on a new object and then slowly rotate backward again. This eye movement is called nystagmus. If a crew member is rotated about a vertical axis and then suddenly stopped, this causes post-rotational nystagmus, eye movements opposite in direction from normal nystagmus. The otolith organs and the semicircular canals influence the reflex that controls nystagmus. Investigators hypothesize that the reflex will work differently in space. To test this theory, a subject harnessed in a chair rotates for 1 minute, then stops to induce post-rotational nystagmus. Head movements and eye movements are recorded at different rotation levels.

On Earth, the vestibular organs and eyes tell people which way they are moving and how fast. However, visually induced feelings of self motion are inhibited if vestibular signals fail to confirm the motion. Scientists hypothesize that with exposure to weightlessness, people suppress vestibular signals and become more dependent on vision and touch to perceive motion and orientation. On previous missions, a rotating dome with dot patterns made subjects feel like they were rotating in the direction opposite to that of the dome. As expected, subjects reported stronger visual effects and sensations of rotation in space than they did in similar tests on the ground. Researchers have enhanced this experiment and will repeat it on SLS-1. The subject looks into the dome and indicates the direction of perceived motion with a joy stick. Eye and body movements are recorded on video, and a strain gauge measures neck movements.

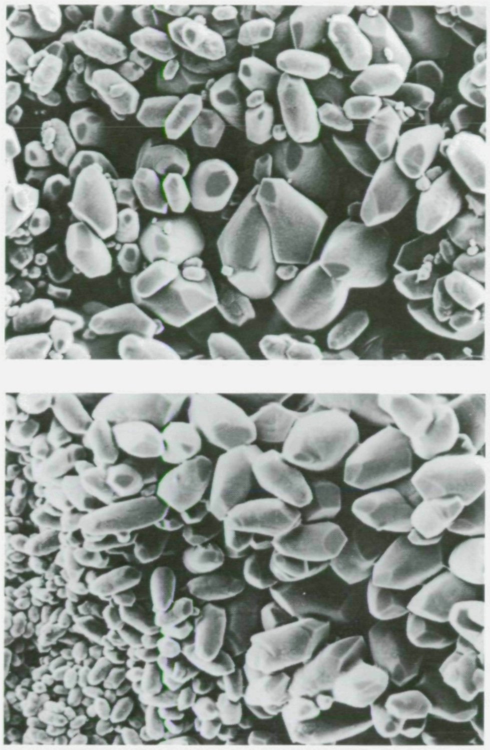
Another experiment examines spinal reflexes to determine whether they change in microgravity. In Earth's environment, the otoliths signal the muscles to prepare for jolts associated with falling. During previous space

The body restraint system is a rotating chair with a harness to hold the test subject in place. The crew member wears an accelerometer and electrodes to record head motion and horizontal and vertical eye movements as the body rotates. Payload Specialist Dr. Byron Lichtenberg and Mission Specialist Dr. Owen Garriott prepare for vestibular experiment activities during Spacelab 1.



Spacelab 1 Payload Specialist Dr. Wubbo Ockels and Mission Specialist Dr. Owen Garriott practice using the rotating dome. The subject bites down on a mouthpiece (biteboard) to position the head correctly within the dome. Elastic cords hold the crew member to the Spacelab floor, providing an orientation cue to the feet. When the dome rotates, the test subject uses a joystick to indicate the perceived direction and velocity of rotation. A strain gauge in the biteboard measures neck rotation, electrodes sense the activity of neck muscles, and video cameras record eye movements and body positions.

The rotating dome, installed in Spacelab 1, shows the random pattern of colored dots inside the dome.



Otoliths from flight rodents (upper photo) contain more immature calcium crystals than those from ground control subjects (lower photo). Whether microgravity slows down crystal maturation or speeds up immature crystal proliferation is a question researchers hope to answer during SLS-1.

Although it is impossible to fall in space, a system of cords and releases produces a downward acceleration so that investigators can measure human reflexes in microgravity. Payload Specialist Dr. Byron Lichtenberg performs a drop experiment during Spacelab 1.

flight tests, the normal reflex between the otoliths and the muscles was partially inhibited early in flight, declined further as the flight progressed, and returned to normal immediately after landing, suggesting that the brain ignores or reinterprets otolith signals during space flight. Crew members reported a lack of awareness of position and location of feet, difficulty in maintaining balance, and a perception that falls were more sudden, faster, and harder than similar drops experienced preflight. This experiment is repeated on SLS-1. Elastic cords that run from the subject's torso to the floor simulate falls in microgravity. The crew member activates the experiment equipment, and in seconds, the cords pull the subject downward, causing a falling sensation. Electrodes measure muscle electrical activity in the subject's lower legs to determine the nervous system's reaction.

On previous flights, subjects have experienced illusions as they performed prescribed movement tests. When crew members viewed various targets and then pointed at them while blindfolded, their perception of target location and the position of their own limbs was inaccurate in flight compared with similar tests on the ground. A revised version of this experiment is repeated on SLS-1, and video recordings are made as subjects express their awareness of limb positions, posture, and target locations.

The experiment, **A Study of the Effects of Space Travel on Mammalian Gravity Receptors (Exp. No. 238)** developed by Dr. Muriel D. Ross of the NASA Ames Research Center, Moffett Field, California, investigates structural changes that may occur within the inner ear in response to the negligible gravity of space. The investigation seeks to define the effects of prolonged weightlessness on the small, calcified gravity receptors called otoliths. Scientists suspect that otolith degeneration may occur as a result of changes in the body's calcium levels, carbohydrate and protein metabolism, body fluid distribution, and hormone secretions.

After the mission, otolith organs from several rodents are compared with otoliths from ground-control rodents. Electron microscopes produce three-dimensional images of the gravity receptors, and a computer system records the images on a laser disk for analysis. Investigators then compare the images to see if any of the gravity receptors exhibit changes that might be attributed to space flight. A week

later, scientists analyze otoliths from the remaining rodents to determine whether the otoliths recover or progressively degenerate.

SLS-1 is the first mission to carry jellyfish as part of its payload. In a two-part investigation designed by Dr. Dorothy B. Spangenberg of the Eastern Virginia Medical School, Norfolk, Virginia, **The Effects of Microgravity-Induced Weightlessness on Aurelia Ephyra Differentiation and Statolith Synthesis (Exp. DCL)**, the gravity receptors of jellyfish are studied to determine how microgravity influences their development and function. Jellyfish and other invertebrates use structures called rhophalia to maintain their correct orientation in water. Rhophalia have statoliths that are analogous to mammalian otoliths.

Jellyfish polyps are contained in bags and flasks of artificial seawater. Crew members inject controlled amounts of thyroxine or iodine into the bags during the mission, inducing the polyps to metamorphose into free-swimming ephyrae (a tiny form of the jellyfish). After 6 or 7 days, crew members fix some of the bags and stow them in the Spacelab refrigerator. Some of the other bags and flasks are filmed; during the last 2 days the ephyrae showing the greatest degree of maturity are filmed to observe their swimming behavior in weightlessness. A simultaneous ground control experiment parallels the flight activities. After the mission, investigators examine both sets of live and fixed jellyfish and compare them for changes in morphology, calcium, and statolith size, shape, and number. Postflight analyses determine whether microgravity also accelerates the demineralization of the statoliths in jellyfish exposed to thyroxine.

To determine the function of the statoliths and adaptation of the jellyfish ephyrae to microgravity, investigations will compare the swimming behavior of tiny jellyfish metamorphosed in space with those ephyrae metamorphosed on Earth. ■

Neurovestibular System Investigator Teams

EXPERIMENT NO. 072

Principal Investigator:

Dr. L.R. Young
Massachusetts Institute of Technology
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Co-Investigators:

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University of Illinois, Chicago, Illinois

Dr. B.K. Lichtenberg
Payload Systems, Inc., Wellesley, Massachusetts

Dr. K.E. Money
D.C.I.E.M., Downsview, Ontario, Canada

Dr. C.M. Oman
Massachusetts Institute of Technology
Cambridge, Massachusetts

Dr. D.G.D. Watt
McGill University, Montreal, Quebec, Canada

EXPERIMENT NO. 238

Principal Investigator:

Dr. M.D. Ross
NASA Ames Research Center, Moffett Field, California

Co-Investigator:

Dr. L. Cutler
NASA Ames Research Center, Moffett Field, California

EXPERIMENT DCL

Principal Investigator:

Dr. D.B. Spangenberg
Eastern Virginia Medical School, Norfolk, Virginia

Scientists developed special bags and flasks with syringes for the jellyfish experiment. Thyroxine, iodine, and specimen fixatives are isolated by syringes and can only come in contact with the jellyfish medium when a crew member purposely breaks seals in the syringes.

Other Investigations

The primary SLS-1 experiments investigate the biology of humans and other animals in space, but some secondary studies are included to gather data that complement the major investigations or to develop space facilities for future missions. For example, the instrument operations and experiment protocols on SLS-1 will influence the design of equipment and procedures for the planned Health Maintenance Facility and Life Science Research Facility on Space Station Freedom.

The Research Animal Holding Facility is a prototype rodent habitat for Space Station Freedom.

Particulate Containment Demonstration Test

Although the SLS-1 crew members do not handle the flight rodents, on subsequent missions the crew may transfer animals to work stations for laboratory procedures. In preparation for these activities, NASA has designed facilities for housing, carrying, handling, and measuring animals and has developed procedures for efficient operations and for the comfort and safety of both the crew and the animals.

A Research Animal Holding Facility (RAHF) contains 12 rodent cages, each of which can house two laboratory rats. The facility contains all food, water, environmental, and sanitation arrangements for each of its inhabitants and permits access to the animals if the need arises. A monitoring system gathers feeding, activity, and environmental data. During the SLS-1 mission, the RAHF carries 20 rats in a demonstration of its capability to adequately house rodents and to contain the debris that they produce during a mission.

In the Shuttle middeck, nine rats occupy two Animal Enclosure Modules (AEMs). The AEMs increase flight opportunities for passive animal experiments in the Shuttle. These modules differ from the RAHF in that they hold up to five rodents, the crew cannot access animals, and no data are gathered automatically. Like the RAHF, the AEMs provide ventilation, waste containment, water, and food for the mission. Investigators compare animals living in the AEMs with those in the RAHF to evaluate the modules as animal maintenance and housing facilities.

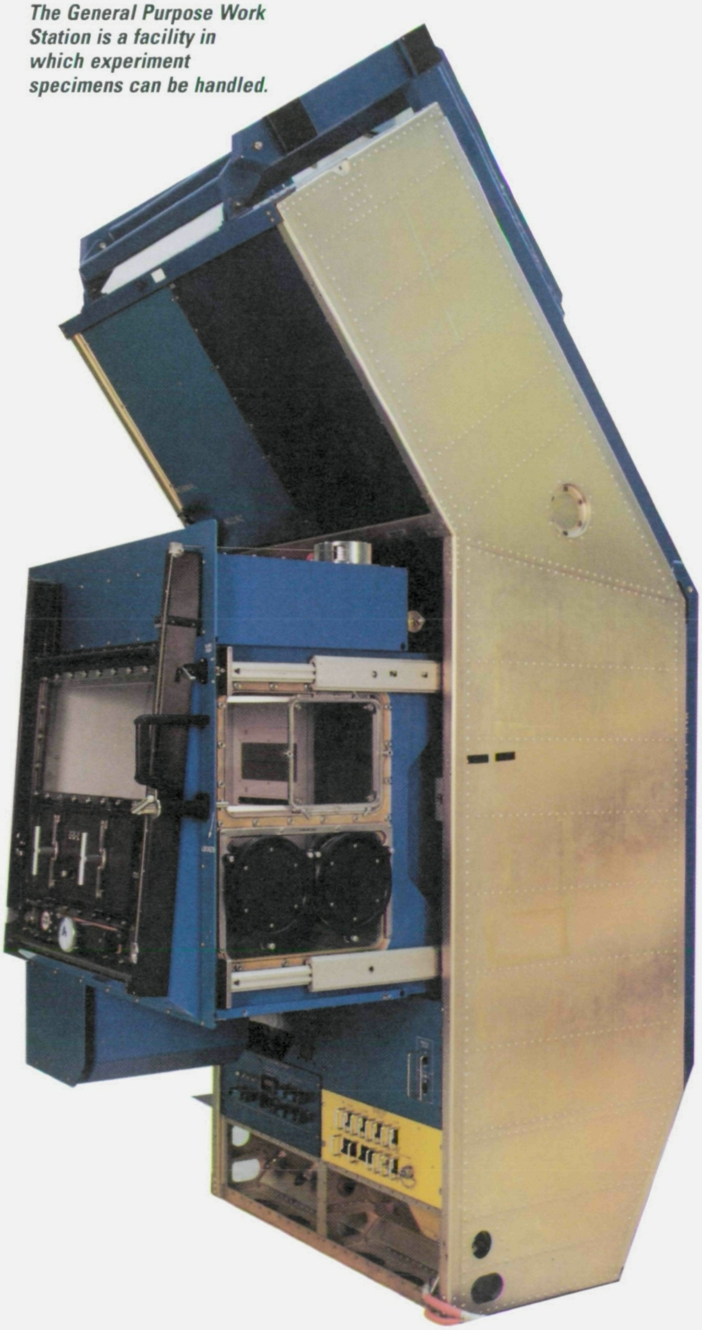
When future rodent investigations call for the crew to service a holding cage or to handle laboratory animals, the crew must be able to

access the cage and transport animals from the holding facilities to a work station without releasing debris into the Spacelab. The General Purpose Transfer Unit (GPTU), a sock-like bag that affixes to the RAHF cage module and to the access window of the General Purpose Work Station (GPWS), contains rodent cages during animal transfer operations. During SLS-1, the effectiveness of the GPTU is demonstrated by the transfer of one empty RAHF cage to the work station.

The work station itself is a closed, retractable cabinet for laboratory activities that require the crew to handle chemicals and manipulate samples. Crew members can introduce samples into the GPWS through a side access door and handle the specimen through gauntlets in the front of the enclosure. A mesh grill and forced air flow keep solid particles, liquid spills, and gaseous contaminants within the cabinet. The work station is a prototype for an animal laboratory facility aboard Space Station Freedom.

During the Particulate Containment Demonstration Test, developed by NASA Ames Research Center, representative 10-day accumulations of food crumbs, rat hair, and simulated rodent wastes are released both into the work station and two empty RAHF cages to verify their ability to contain animal debris. The GPWS is also evaluated for fluid containment as colored water is released within the cabinet to simulate spills and animal urination. After these facility tests, the crew remove one of the cages from the RAHF, move it to the work station in the transfer bag, and place it in the cabinet through the access window. The Shuttle environment is monitored for escaping contaminants by an air sampler, photography, and crew observations and comments.

The General Purpose Work Station is a facility in which experiment specimens can be handled.



SLS-1 Mission Specialist Dr. Rhea Seddon practices using the Small Mass Measurement Instrument. On future flights, crew members will use this device to monitor changes in the mass of small animals or to determine the mass of tissue samples.

Small Mass Measurement Instrument

One measure of health is weight gain or loss during space flight; however, in the weightless environment of the orbiting Shuttle, scientists substitute measurements of mass for measurements of weight. A major instrument for the second SLS mission, the Small Mass Measuring Instrument for small animals and tissue samples, is to be calibrated during SLS-1. By ascertaining the stability of the device during SLS-1, the time required to recalibrate the instrument on later missions will be minimal. The experiment uses calibration masses similar to those of flight rodents.

Surgical Work Station

Two pieces of medical equipment that are to be incorporated into the Health Maintenance Facility for Space Station Freedom are to be verified aboard SLS-1. The Health Maintenance Facility will be the site for the more comprehensive health monitoring activities, diagnoses, and treatments required during long missions. SLS-1 crew members evaluate the effectiveness and convenience of the restraining features of a surgical work station, including a restraint surface for the patient, a restraining belt for the medical officer, and a table for instruments and equipment. The two principal investigators for this demonstration are Dr. David K. Broadwell, Project Manager for the Health Maintenance Facility, NASA Johnson Space Center, Houston, Texas, and Dr. Bruce A. Houtchens, the University of Texas Health Science Center at Houston, Houston, Texas.

Spacelab 1 Mission Specialist Dr. Robert Parker and Payload Specialist Dr. Ulf Merbold perform biomedical tests while floating freely. Spacecraft for long missions will have a station for performing more intricate medical activities than have been required for the shorter Spacelab flights, and restraints at the surgical work station will free the crew member's arms and hands for complicated procedures.

Intravenous Pump

The second instrument to be evaluated is a pump for intravenous infusions. Many medical techniques involving fluid transfers, such as intravenous procedures, make use of Earth's gravity in their operations, but because fluids behave differently in space than on Earth, it is critical to develop instruments that transfer fluids accurately and efficiently in low-gravity. The intravenous infusion pump to be verified uses wavelike contractions, not gravitational attraction, to transport fluid through an occluded tube in much the same way that food moves through the alimentary canal. Crew members validate that the pump can deliver a prescribed amount of fluid at a specific rate. Dr. David K. Broadwell is also the principal investigator for this evaluation.

Airborne Particles

Shuttle crew members have reported occasional eye and respiratory tract irritation from debris floating in living and working areas. An environmental monitor collects respirable particles from the air for postflight analysis. Investigators identify the airborne materials, calculate their concentrations, and identify possible contaminating sources. Findings from this investigation will be used to assess the effectiveness of the Shuttle's current environmental control and life support system and to develop environmental monitoring system standards for long-duration flights. Dr. Dane Russo of the NASA Johnson Space Center, Houston, Texas, is the principal investigator.

Noninvasive Central Venous Pressure

Another investigation evaluates a noninvasive technique for measuring central venous pressure. To track changes in central venous pressure during the flight, a crew member breathes into a specially designed mouthpiece that creates resistance to exhaled air. By monitoring the pressure in the mouthpiece and monitoring blood flow in the jugular vein, scientists can calculate the central venous pressure. If these noninvasive measurements are consistent with those made by intravenous catheters, it will be easier and more convenient to gather body fluid data from experiment subjects and to monitor the cardiovascular health of the crew. Dr. J.B. Charles of NASA Johnson Space Center, Houston, Texas, is the principal investigator.

Space Acceleration Measurement System

The Space Acceleration Measurement System enhances SLS-1 science data return by making more sensitive measurements of acceleration than similar orbiter instruments. Many of the SLS-1 investigations, particularly the neurovestibular experiments, use these data to complement their specific biological measurements. Three sensors are located in different areas of Spacelab (on the SMIDEX support structure, near the Solid Surface Combustion Experiment within SMIDEX, and on the floor near the bicycle ergometer) to measure microgravity accelerations. The Space Acceleration Measurement System was developed by NASA Lewis Research Center, Cleveland, Ohio.

Solid Surface Combustion Experiment

Crew and payload safety is a primary emphasis of all space programs. A microgravity science investigation that complements life sciences research, the Solid Surface Combustion Experiment, is also aboard SLS-1. This investigation studies how flames produced by solid fuels behave in microgravity. These findings will influence the selection of materials suitable for spacecraft architecture and the development of operating procedures when flammable materials are present. The principal investigator is Dr. R.A. Altenkirch of Mississippi State University, Mississippi State, Mississippi. ■

Congressman Bill Nelson, a Payload Specialist on Shuttle flight 61-C, used the noninvasive central venous pressure equipment to measure the time course of changes in central venous pressure during flight.

The SLS-1 Crew

The SLS-1 crew has seven members: a commander, a pilot, and three mission specialists who are all NASA astronauts and two payload specialists who are professional scientists. The commander, the pilot, and one of the mission specialists are the orbiter flight crew who manage Shuttle operations. The other two mission specialists and the payload specialists work together as the science crew; they have been trained to serve as both subjects and operators for each experiment.

Mission Specialists

From its cadre of astronauts, NASA selected two mission specialists with medical expertise, Dr. James P. Bagian and Dr. M. Rhea Seddon. As career astronauts, mission specialists are qualified to operate Shuttle systems and are responsible for operating and maintaining Spacelab systems. As scientists, they collaborate with the principal investigators and payload specialists to conduct experiments.

Flight Crew

Every Shuttle flight is guided by the leadership of a veteran NASA astronaut, the commander. Commander Col. Bryan D. O'Connor is ultimately responsible for all mission activities. In addition to flying the Shuttle, the commander ensures that all operations are carried out safely and efficiently. Pilot Col. John E. Blaha assists the commander with Shuttle flight operations. Mission specialist Dr. Tamara E. Jernigan serves as the flight engineer during dynamic phases of the flight. The flight crew are not trained to do specific experiments, but they may help during some experiment operations.

Payload Crew

Members of the SLS-1 payload crew were chosen for their expertise in the biological sciences. Life sciences research in space demands a crew that can serve as skilled investigators, test subjects, and laboratory technicians. Crew members draw and process blood samples, record their own physiological symptoms, set up and participate in a variety of experiments, observe and comment on the behavior of animals, and carry on their work much as they do in laboratories on the ground.

The science crew members have extensive medical and research experience supplemented by years of training for this mission's investigations. They are well-acquainted with the goals and operations of each experiment and skilled in making accurate scientific judgments.

COL. BRYAN D. O'CONNOR (USMC), Commander, earned an M.S. in aeronautical systems from the University of West Florida and a B.S. in engineering from the United States Naval Academy. He was selected as an astronaut in 1980. On the 61-B Space Shuttle mission in 1985, O'Connor piloted the Shuttle during spacewalks to demonstrate space construction techniques, helped deploy communication satellites, conducted experiments, and tested new Shuttle systems. He has served as the assistant Shuttle program manager and as chairman of NASA's Space Flight Safety Panel. The SLS-1 mission is his second flight.

MAJOR SIDNEY M. GUTIERREZ (USAF), Pilot, received an M.A. in management from Webster College and a B.S. in aeronautical engineering from the United States Air Force Academy. He was selected as an astronaut in 1984. Gutierrez first served as a Commander for the Shuttle Avionics Integration Laboratory (SAIL), flying simulated missions to verify flight software. In 1986 he served as an Action Officer for the Associate Administrator for Space Flight and then participated in the recertification of the Shuttle main engines and external tank. Most recently, Gutierrez has supported launch activities at the Kennedy Space Center. SLS-1 is his first mission.

DR. TAMARA E. JERNIGAN, Mission Specialist, received a Ph.D. in space physics and astronomy from Rice University. After graduating from Stanford University with a B.S. in physics, Dr. Jernigan worked in the Theoretical Studies Branch at NASA Ames Research Center. Her studies included star formation, gamma ray bursters, and shock wave phenomena in the interstellar medium. Since 1985, when she was selected as an astronaut, her duties have included software verification of certain Shuttle systems, coordination of secondary payloads, and support of Shuttle flights from the Mission Control Center as Capsule Communicator (CAPCOM). The SLS-1 mission is her first flight.

Payload Specialists

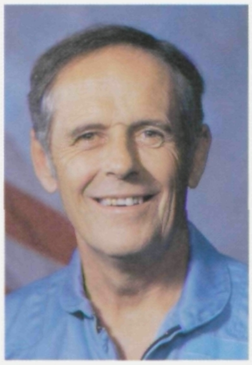
The three SLS-1 payload specialists are Dr. Francis Andrew Gaffney, Dr. Robert Ward Phillips, and Dr. Millie Hughes-Fulford. These scientists were selected by their peers to do experiments in space. All have broad life sciences backgrounds with complementary expertise in the areas of cardiovascular research, veterinary science, and metabolic processes.

Drs. Gaffney and Phillips have been selected to fly on SLS-1. Dr. Hughes-Fulford is the alternate payload specialist; during the mission she plays an important role supporting the crew from the Payload Operations Control Center on the ground. After years of training, the alternate payload specialist is familiar enough with crew procedures to give essential assistance and to communicate crew needs to the mission management team and the investigators. Dr. Hughes-Fulford is scheduled to serve as a flight payload specialist on the second SLS mission. ■

DR. JAMES P. BAGIAN, Mission Specialist, has an M.D. from Thomas Jefferson University and a B.S. in mechanical engineering from Drexel University. He began his career with NASA in 1978 when he went to work at Johnson Space Center as a flight surgeon and research medical officer. In 1980, he became a NASA astronaut. Dr. Bagian took part in the planning and provisioning of emergency medical and rescue support for the first six Shuttle flights. He assisted in the development of a variety of Shuttle payloads, served as astronaut coordinator for Space Shuttle payload software and crew equipment, and helped develop the pressure suit and other crew survival equipment for Shuttle missions. He supported the development of animal holding facilities for SLS-1. On his first flight, STS-29, he helped deploy a major NASA communications satellite and did scientific research.

DR. M. RHEA SEDDON, Mission Specialist, earned an M.D. from the University of Tennessee College of Medicine and a B.A. in physiology from the University of California, Berkeley. While working as a physician and surgeon, she researched the effects of radiation therapy on nutrition in cancer patients. NASA selected her as an astronaut candidate in 1978. At NASA, she supported the development of orbiter and payload software, helped design the Shuttle medical kit and checklist, served as physician for the launch and landing rescue helicopter, was a support crew member for STS-6, and Technical Assistant to the Director of Flight Crew Operations. Dr. Seddon made her first space flight as a mission specialist on Shuttle flight 51-D in 1985; during the flight, she completed life sciences experiments, operated the Remote Manipulator System, and launched a satellite. SLS-1 is her next assignment.

DR. FRANCIS ANDREW (DREW) GAFFNEY, Flight Payload Specialist, received an M.D. from the University of New Mexico. He is an associate professor of medicine at the University of Texas Health Science Center in Dallas. He is also a practicing physician and serves as Director of Echocardiography for Parkland Memorial Hospital. Dr. Gaffney has published more than 70 papers and abstracts on cardiology, hypertension, exercise physiology, echocardiography, and related subjects. His 15 years of experience in cardiac research and the operation of equipment such as echocardiographs and rebreathing devices make him well-qualified to operate similar equipment developed for SLS-1. Dr. Gaffney is a co-investigator on a mission experiment that studies human cardiovascular adaptation to space flight.



DR. ROBERT WARD PHILLIPS, Flight Payload Specialist, is a professor of physiology at Colorado State University. He earned a doctorate in veterinary medicine from Colorado State University and a Ph.D. in physiology from the University of California. He has almost 30 years of experience in physiological and nutritional research involving both humans and animals. He has published more than 100 papers on subjects such as the musculoskeletal system, metabolic processes, fluid and electrolyte shifts, diabetes mellitus, endocrine toxic shock, and nutrition. Dr. Phillips' animal studies were useful in developing laboratory equipment for SLS-1 small animal research.

DR. MILLIE HUGHES-FULFORD, Alternate Payload Specialist, is a research chemist at the San Francisco Veterans Administration Hospital and an associate professor of biochemistry in the Department of Medicine at the University of California in San Francisco. She has a Ph.D. in chemistry from the Texas Women's University. Dr. Fulford has 15 years of experience in cancer research and metabolic processes. She has published more than 58 papers and abstracts on radiation chemistry, cell differentiation and growth, DNA synthesis, cholesterol metabolism, enzyme regulation, metabolic skin disorders, and chemotherapy. Her experience in the design and operation of chemical and biological laboratory instruments and her research with both humans and small animals are assets for the SLS-1 mission.

Mission Management and Development

Preparing a payload for flight aboard the Shuttle and Spacelab is a complex, interactive effort involving many NASA organizations that work together as a team to make the mission a success. Years before launch, managers, engineers, and scientists are busy planning and organizing activities to flow smoothly during a Spacelab mission.

Experiment Selection

To place an investigation on Spacelab, scientists engage in a tough competition judged by their peers. In 1978, NASA Headquarters issued an Announcement of Opportunity requesting proposals for flight experiments that would fulfill the goals of the SLS-1 mission. The international scientific community responded with enthusiasm, submitting almost 400 proposals.

An independent panel of eminent scientists reviewed the scientific merit of each proposal. During a subsequent feasibility study, NASA reviewed the suitability of each experiment for flight aboard the Shuttle/Spacelab; this panel defined each experiment's scientific objectives and requirements, including data collection, hardware development, testing and integration, crew training, and inflight operations. Some 100 proposals were selected for further evaluation by a Life Sciences Steering Committee that rated each experiment's scientific and technical merit and decided whether it was pertinent to Life Sciences Flight Experiment Program goals. To ensure that SLS-1 was an integrated payload composed of complementary investigations, preference was given to experiments that addressed significant questions regarding adaptation to microgravity or fundamental biological issues. Based on this review, the NASA Headquarters Space Sciences Steering Committee recommended investigations to the NASA Associate Administrator for Space Sciences who made the final decision to approve the current SLS-1 payload.

Experiment Development

For the next phase, experiment hardware development, NASA Headquarters assigned each experiment to a NASA project office. The JSC project office developed all the SLS-1 human experiments, and the ARC project office developed all the non-human experiments. The project offices at these centers are responsible for providing new experiment hardware as well as core equipment from the life sciences hardware inventory.

The principal investigator for each experiment works with a project office to define costs, schedules, and plans for designing, fabricating, and testing hardware. Facts that ground-based researchers do not have to consider become critical to the flight investigator: the unique space environment; weight, size, and power limitations; limited sample sizes; and hands-on activity. Comprehensive experiment requirements documents explain the approach for doing each experiment and identify the specific scientific measurements to be obtained and the resources needed to accomplish each investigation.

Hardware development begins with formal design reviews and culminates with hardware acceptance. The project office must assure that the hardware complies with NASA safety requirements, fits in the Spacelab, and operates properly in the Shuttle/Spacelab environment. Once a final design is approved, the project office establishes plans for hardware fabrication, testing, checkout, acceptance, and safety verification. Operating procedures and experiment techniques are developed while each instrument is being designed.

Mission Management

The main objective of mission management is to assemble selected experiments and support equipment into a composite payload that is compatible with Spacelab capabilities and consistent with payload program objectives. All the diverse elements of the payload must be organized to optimize resources and maximize scientific yield. NASA Headquarters designated JSC as the center to manage the SLS-1 mission. The JSC mission manager and his team do detailed planning and implementation for the payload, control schedules and funding, and work with other organizations to carry out the mission.

Participating scientists have a voice in guiding Spacelab missions. The principal investigators, who are the chief scientists for each experiment selected for flight, form an Investigator Working Group and convene periodically to help plan the mission. They identify scientific goals, help select and train the payload crew, and monitor experiments during the mission. The NASA mission scientist, who is a crucial member of the mission management team, chairs the group, and payload project managers and scientists from both JSC and ARC participate in the committee's decisions.

The mission management team also coordinates activities with the Space Transportation Office at NASA Headquarters. This office assigns payloads to specific Shuttle flights. The Shuttle Payload Integration Development Office at JSC works with the mission manager to write the Payload Integration Plan. This plan is based on agreements established between the mission manager and the principal investigators and covers every aspect of the mission: payload installation, interfaces between the payload and the Shuttle, requirements of the Shuttle to carry out the mission, flight activities, management responsibilities, payload design, mission operations, environmental analyses, launch and landing site support, safety, and postflight data requirements.

Mission Design

The SLS-1 mission manager identifies how the experiments and hardware fit in the Spacelab module and Shuttle middeck. Experiments are grouped based on scientific, engineering, and operational considerations. Matching experiment requirements developed by the project offices and the principal investigators with the capabilities of the Spacelab, the mission management team allocates each experiment so much weight, room in the Spacelab, power, and crew time.

A master blueprint defines the location and layout of experiment hardware and support equipment. The team determines what interfaces are needed to put each experiment inside the Spacelab module and specifies the interfaces to the project office designing the experiment hardware. Engineering analyses are completed to establish the structural and thermal compatibility of specific hardware with Spacelab.

The mission management team also decides what hardware and personnel are needed to support the flight from the ground, helps develop procedures for operating the experiments, plans crew activities, and assesses safety considerations. To implement the mission design, the team builds unique support hardware, develops software, tests and verifies hardware installation in the Spacelab, prepares a timeline of mission events, and trains the flight and ground crews.

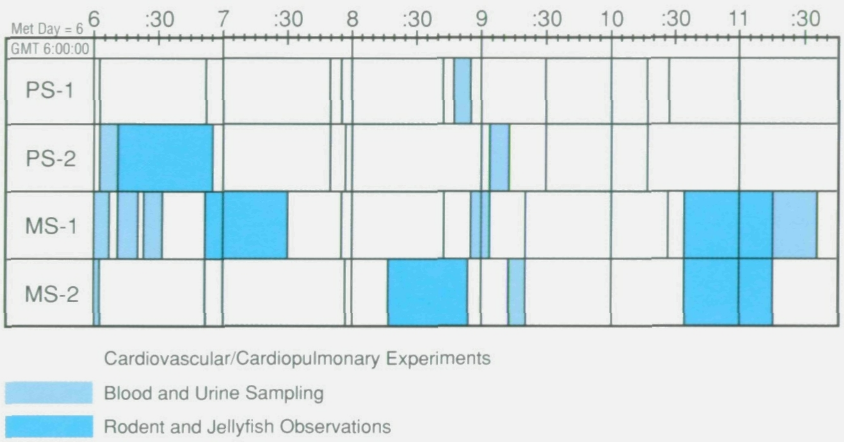
The SLS-1 Team

NASA Headquarters Office of Space Science and Applications (OSSA)
Program Manager: Mr. G.W. McCollum, Flight Systems Division
Responsibilities: directs all activities, identifies program goals and objectives, and ensures that mission requirements are understood, approved, and budgeted
Life Sciences Program Manager: Mr. W.P. Gilbreath, Life Sciences Division
Reponsibilities: directs all activities, identifies program goals and objectives, supports the development of experiment hardware, funds investigator teams, and ensures that the mission requirements are understood, approved, and budgeted
Program Scientist: Dr. R.J. White, Life Sciences Division
Responsibilities: establishes the mission science objectives, solicits and selects experiments, and oversees publishing of scientific results
Johnson Space Center (JSC) Mission Management Office
Mission Manager: Mr. W.D. Womack, Mission Management Office
Responsibilities: defines, designs, and implements the SLS-1 mission; uses NASA Headquarters guidelines to establish the mission's policies and requirements, defines rules for mission integration and operation, identifies and controls resources, reviews and assesses the technical progress of the program, and coordinates activities with all the NASA offices and principal investigators participating in the mission
JSC Space and Life Sciences Directorate
Mission Scientist: Dr. H.J. Schneider, Mission Science Office
Responsibilities: serves as the liaison between the experimenters and the mission management team and ensures that mission science objectives are met with maximum scientific yield
JSC and Ames Research Center (ARC) Project Offices
Project Managers: Mr. J.B. Walters, JSC Life Sciences Project Division Ms. B.P. Dalton, ARC Space Life Sciences Payloads Office
Project Scientists: Dr. M.C. Buderer, JSC Life Sciences Project Division Dr. G.C. Jahns, ARC Space Life Sciences Payloads Office
Responsibilities: coordinate activities with principal investigators including experiment hardware development and experiment requirements definition; support mission flight operations, crew training, and other payload processing activities

Mission Timeline

Before every mission, NASA prepares a schedule of events, called a timeline. The SLS-1 timeline is busy, and every minute is scheduled. SLS-1 is one of the most crew-intensive Spacelab missions to date because all payload crew members act as both experiment operators and subjects. Each experiment is assigned time slots during which it receives the necessary power, crew attention, and computer support for its operation. Experiment operations are scheduled to maximize the sharing of data and equipment.

The sequence of experiments is scheduled so that investigators can track the time course of physiological changes. Since many significant changes appear to take place during the first hours of flight, several measurements must be made then. To follow changes through every phase, experiments must be repeated at regular intervals in flight and immediately after landing. During the mission, the timeline can be revised in response to unexpected opportunities, but the guiding philosophy is to adhere as closely as possible to the schedule established before flight.

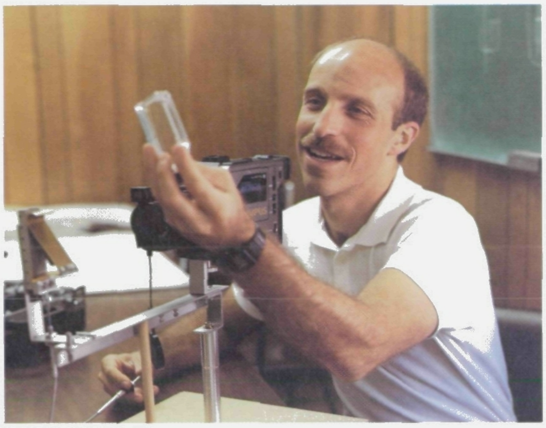


This sample timeline shows a portion of one shift of SLS-1 science operations. The final timeline is a minute-by-minute schedule of every mission activity.

Mission Training

Life sciences research is a human adventure. Without the crew members who serve as test subjects and operators, the experiments would be impossible. Equally important is the interaction between managers, engineers, scientists on the ground, and the onboard crew. By monitoring data, having air-to-ground dialogue, and watching live television from orbit, the people on the ground virtually

SLS-1 Payload Specialists check out the equipment for three experiments during integrated experiment training in this high-fidelity mockup of the Spacelab at the Johnson Space Center. Dr. Hughes-Fulford (left) calibrates the baroreflex hardware; Dr. Phillips (center) calculates his mass in the Body Mass Measurement Device; and Dr. Gaffney (right) prepares the Rebreathing Assembly Unit.



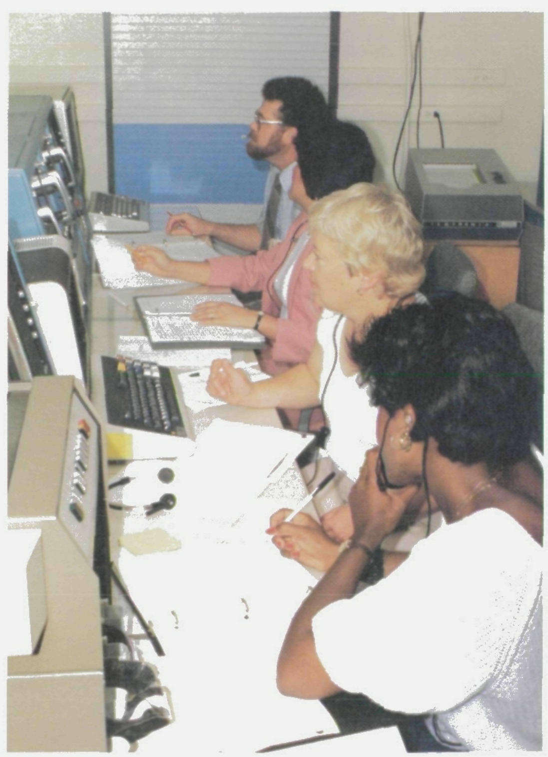
Mission Specialist Dr. James Bagian practices videotaping jellyfish during individual experiment training.

work side-by-side with their colleagues in space. Training is essential to ensure that the mission progressess as planned.

To perform a variety of space experiments for their scientific colleagues, crew members must be thoroughly trained in all aspects of each experiment. Principal investigators brief science crew members in the theory, hardware, and operation of their experiments. The next step is to train with the hardware as it will be configured in the Spacelab. The crew members learn individual experiments, and then they practice doing all experiments.

The last step is practicing the experiments exactly as they will be done in space. During the year before the mission, the science crew, the principal investigators, project office personnel, and the mission management team participate in integrated mission training. Critical portions of the mission are simulated so that the crew and ground support personnel can rehearse operations. Simulated inflight operations take place inside the JSC Mission Integrated Training Facility, which contains a realistic mockup of the SLS-1 module. This simulator is outfitted with backup experiment flight hardware and some simulated hardware. The ground support team monitors experiments from simulated control centers, and the crew members complete the experiments, just as they do during the mission. Various problems are introduced, and the crew and ground support team must solve the problems and replan mission activities.

Crew members also must learn the basic skills necessary for living and working safely on board the Shuttle and Spacelab. In astronaut training programs at JSC and Kennedy Space Center (KSC) in Florida, they learn the medical, emergency, and survival skills and the normal routines of living in a spacecraft.



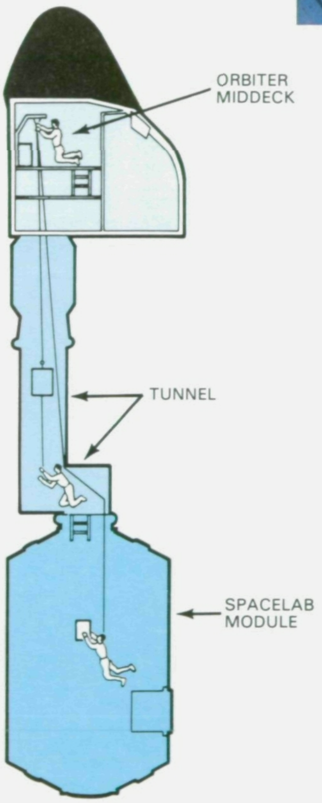
Participants in ground control simulations check data on their consoles in the Science Monitoring Area.

Technicians at Kennedy Space Center install experiment hardware in racks that fit inside the Spacelab

Payload Integration

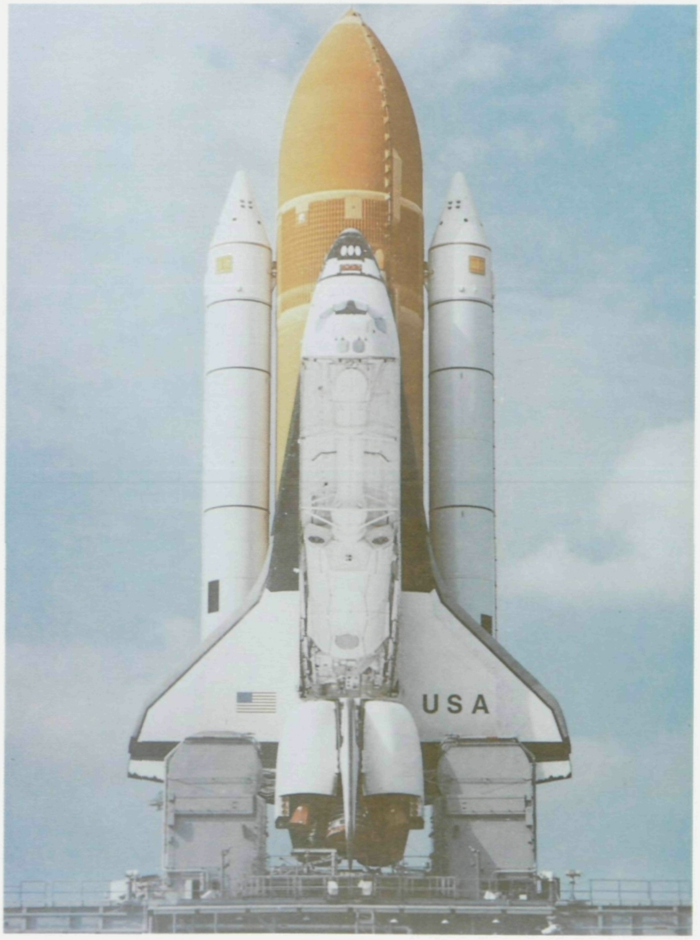
A year before the flight, there is intense activity to prepare for the launch. When each piece of experiment hardware is completed, it is shipped to KSC. According to the master blueprint developed by the mission management team, the total payload is assembled and installed in the Spacelab. Here, the payload is subjected to many tests to verify that all the hardware is installed properly and operates correctly.

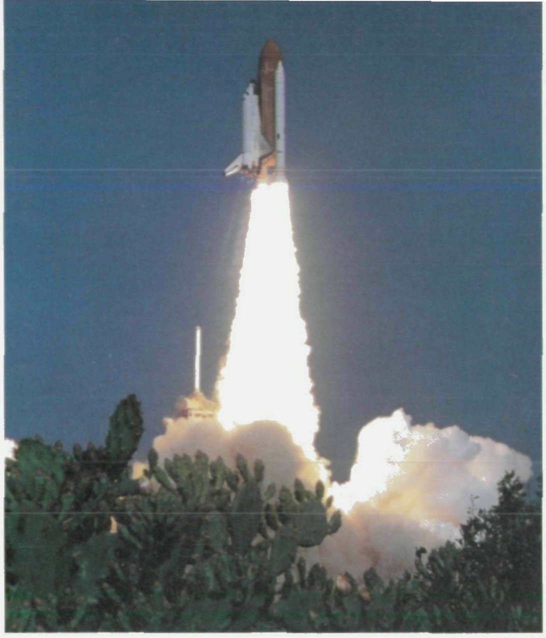
About a month before launch, Spacelab is placed inside the Shuttle, all connections between the orbiter and the laboratory are checked, and the Shuttle is moved to the launch pad. About 22 hours before launch, the animals are loaded. A special system of pulleys and platforms called the Module Vertical Access Kit is used to lower technicians inside the Shuttle/Spacelab, which by this time is upright on the launch pad. The technicians carefully place animals in their housing facilities.



Using the Module Vertical Access Kit, a special rig that allows late entry into the Spacelab module, technicians enter the Shuttle shortly before launch to place animals in their middeck and Spacelab accommodations.

On the launch pad at Kennedy Space Center, Spacelab is vertical in the Shuttle payload bay, as shown in this composite photograph.





The rewards of years of planning and preparation begin as the orbiter Columbia is launched from Kennedy Space Center.

Principal investigators and their ground support teams follow Spacelab activities in the Science Monitoring Area at Johnson Space Center.

Mission Operations

During the flight, all the months of preparation come to a focus as personnel on the ground work in concert with the crew in space to complete the mission objectives. Shuttle operations are directed from the Mission Control Center at JSC, and close contact is maintained with the mission management team stationed in the Payload Operations Control Center (POCC) at Marshall Space Flight Center in Huntsville, Alabama.

From the POCC, the mission manager, the mission scientist, and other key members of the SLS-1 team oversee the full range of Spacelab operations. The POCC contains banks of television monitors, computers, and communications consoles. The payload flight operations cadre assesses and responds to up-to-the-minute information, replans as necessary, advises the crew of changes in the schedule, and works to solve problems and keep the mission flowing smoothly.

For scientists, flying experiments on Spacelab is the next best experience to doing their own research in orbit. Spacelab transports the scientists on the ground to space in a way not possible by other research methods. Investigators monitor experiments minute by minute, analyze results as experiments happen, and if necessary help adjust experiment operations to increase scientific return. Some scientists monitor experiments from the POCC while others work in the Science Monitoring Area, a work station at JSC that is equipped with the tools needed to monitor and analyze life sciences data. Other investigators support the mission from Hangar L at KSC and the Life Sciences Payload Receiving Facility at Edwards Air Force Base, California, which are both designed for preparing biological experiments for flight, for doing ground control experiments simultaneously with flight experiments, and for analyzing data. Data are transmitted from Spacelab to these work areas, and video

The SLS-1 team manages the mission from the Payload Operations Control Center at Marshall Space Flight Center.

Activity in the Mission Control Center at Johnson Space Center focuses on Shuttle operations.

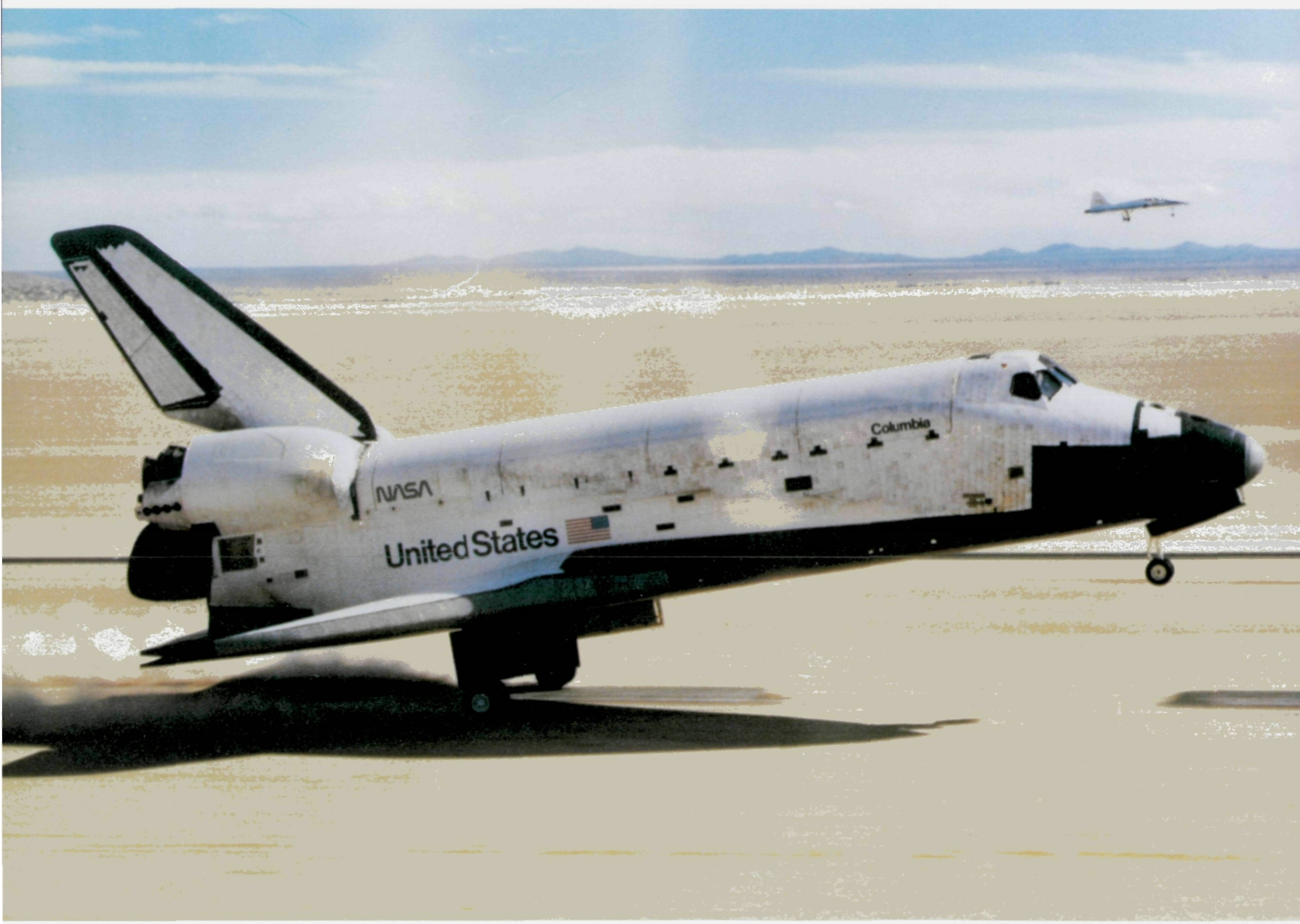
and audio communications make it possible for scientists on the ground to follow the progress of their research and talk with the crew if necessary. All data are recorded, and investigators may request computer tapes, voice recordings, and videotapes that contain information about their experiments.

After the Shuttle lands, the crew members depart to medical facilities for short examinations. Payload crew members participate in the postflight portions of the experiments. Technicians remove samples and experiment equipment from Spacelab and the Shuttle middeck. Specimens such as blood samples and cultures are given immediately to investigators for analysis. Animals are sent to an ARC Life Sciences Payload Receiving Facility located within minutes of the landing site.

A unique advantage of Spacelab is that the laboratory and the experiment facilities are designed for reuse on future missions. The Spacelab hardware is dismantled, inspected, and if necessary, repaired or modified. Some experiment equipment is returned to the investigators, while some remains in NASA's inventory for future use.

The Spacelab Life Sciences 1 mission undoubtedly will yield many insights into the way people and animals adapt to the space environment. Analyses of all returned data will occupy investigators for years and help make space a safe place to live and work. ■

When Columbia lands at Edwards Air Force Base, eager scientists will begin lengthy, exhaustive analyses of the SLS-1 results.



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National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center

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